

*JET PROPULSION LABORATORY
1982 ANNUAL REPORT*

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A description of work accomplished under a contract between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1 to December 31, 1982.

Cover. A false-color radar image of a swampy coastal region in New Guinea, acquired by JPL's Shuttle Imaging Radar-A (SIR-A). Oceans and rivers are dark blue. The textured appearance of the terrain is due to differences in the density and the type of vegetation.

JET PROPULSION LABORATORY
California Institute of Technology
Pasadena, California

DIRECTOR'S MESSAGE



Dr. and Mrs. Lew Allen

*I*n 1982, JPL continued the record of achievement that has characterized the Laboratory. Highlights of a number of activities are described in this annual report; some of these activities are decade-long programs. Planetary exploration remains the Laboratory's principal thrust.

Voyager 1 continued to operate successfully as it traveled on a trajectory that will bring it to the edge of the solar system in the 1990s. The scientific instruments are providing data on particles and fields in interplanetary space. *Voyager 2* is being prepared for its encounter with *Uranus* in 1986.

The *Galileo* mission to further explore *Jupiter*, its atmosphere, and its

moons, progressed well toward a 1986 launch. The issue of which upper stage will be used to launch *Galileo* from the shuttle was settled, and the spacecraft team was able to move rapidly to make design changes.

Last year, NASA formed a committee of scientists—the Solar System Exploration Committee—to formulate a continuing core program of planetary exploration for the United States, within budgetary and other guidelines. The committee's recommendations indicate that an effective and affordable science program would be feasible and that JPL would continue as the lead center to execute the program in future years. The first new start recommended in that core program is the

2 *Venus Radar Mapper, and design definition work has continued at JPL.*

Results from the Shuttle Imaging Radar-A (SIR-A), the Shuttle Multispectral Infrared Radiometer (SMIRR), and the Seasat oceanographic satellite were highly publicized during the year, bringing much acclaim to the Laboratory and Caltech. Progress continued in energy research tasks, and work began on several new Department of Defense projects.

Planning activities for continued exploration of the solar system hinge on designs for the Mariner Mark II spacecraft and the promising missions it could perform at the outer planets and their moons, or at comets and main-belt asteroids. Another concept for continued planetary exploration at reduced costs involves the adaptation of existing satellites to achieve focused science objectives at bodies in the inner solar system.

A wide array of Earth-orbiting experiments and space shuttle packages will fly in the near future. Observations are being planned for the flight of the Shuttle Imaging Radar-B in 1984. Other upcoming JPL shuttle experiments will measure the Sun's total energy output, study the concentration and flow of chemicals in Earth's stratosphere, and examine the behavior of liquids and cryogens in zero-gravity.

At the end of 1982, JPL had 4,590 employees, with efforts divided about 80 percent toward space exploration, 10 percent toward energy and transportation, and 10 percent toward defense.

Last year it was decided to accept additional defense work, subject to the limitation that no more than 30 percent of the Laboratory's efforts should be directed toward defense projects, ensuring that JPL will remain a NASA center. Work we do accept will be done with the same commitment to excellence, objectivity, and integrity that has characterized JPL's efforts in every field.

As we look toward the future, the planetary exploration program appears to have solid support at a level somewhat lower than that of the past. Energy work is predicted to decrease and national security projects will increase. The balance and diversity of projects the Laboratory undertakes will change, but JPL will continue a vigorous space-science program and will pursue research and development tasks applied to other significant problems of national and global interest.



LEW ALLEN
Director



Delta rocket carrying IRAS into orbit

Voyagers 1 and 2 cruised toward their respective destinations through the past year, with one spacecraft approaching the boundary of the solar system and the other traveling to Uranus, Neptune, and beyond. Though it was a relatively quiet year for JPL's twin probes, the spacecraft continued to return data about interplanetary space.

Galileo, a mission to conduct long-term studies of Jupiter and its moons and to probe the planet's atmosphere, incorporated

program changes brought about by the decision to use the Centaur upper stage to launch the spacecraft from a space shuttle. Development of the Wide-Field/Planetary Camera, part of NASA's Space Telescope, continued with assembly and testing activities. And the efforts of 1982 culminated in early 1983 with the successful launch of the Infrared Astronomical Satellite, a joint project involving JPL, the Netherlands, and the United Kingdom.

GALILEO

Galileo is a mission designed to greatly expand the scientific discoveries made by the Voyagers at Jupiter. An orbiter spacecraft will observe the planet and 11 of its moons in detail for 20 months, and an instrumented probe will plunge into the Jovian atmosphere. The combined orbiter and probe are scheduled for launch from a space shuttle in May 1986, using a Centaur upper stage.

In January 1982, plans called for Galileo to be launched from a shuttle in combination with the Air Force's Inertial Upper Stage (IUS). Use of the IUS would have required a May 1985 launch and an Earth-gravity assist (including a two-year orbit around the Sun) for arrival at Jupiter in 1989.

Work on systems designed for use with the IUS was halted in July, however, when Congressional action directed that the Centaur upper stage be used instead. The Centaur is a higher-energy launch vehicle and allows a direct flight to Jupiter. Although Galileo's launch date is now scheduled for a year later, the spacecraft will arrive at Jupiter a year earlier, in 1988.

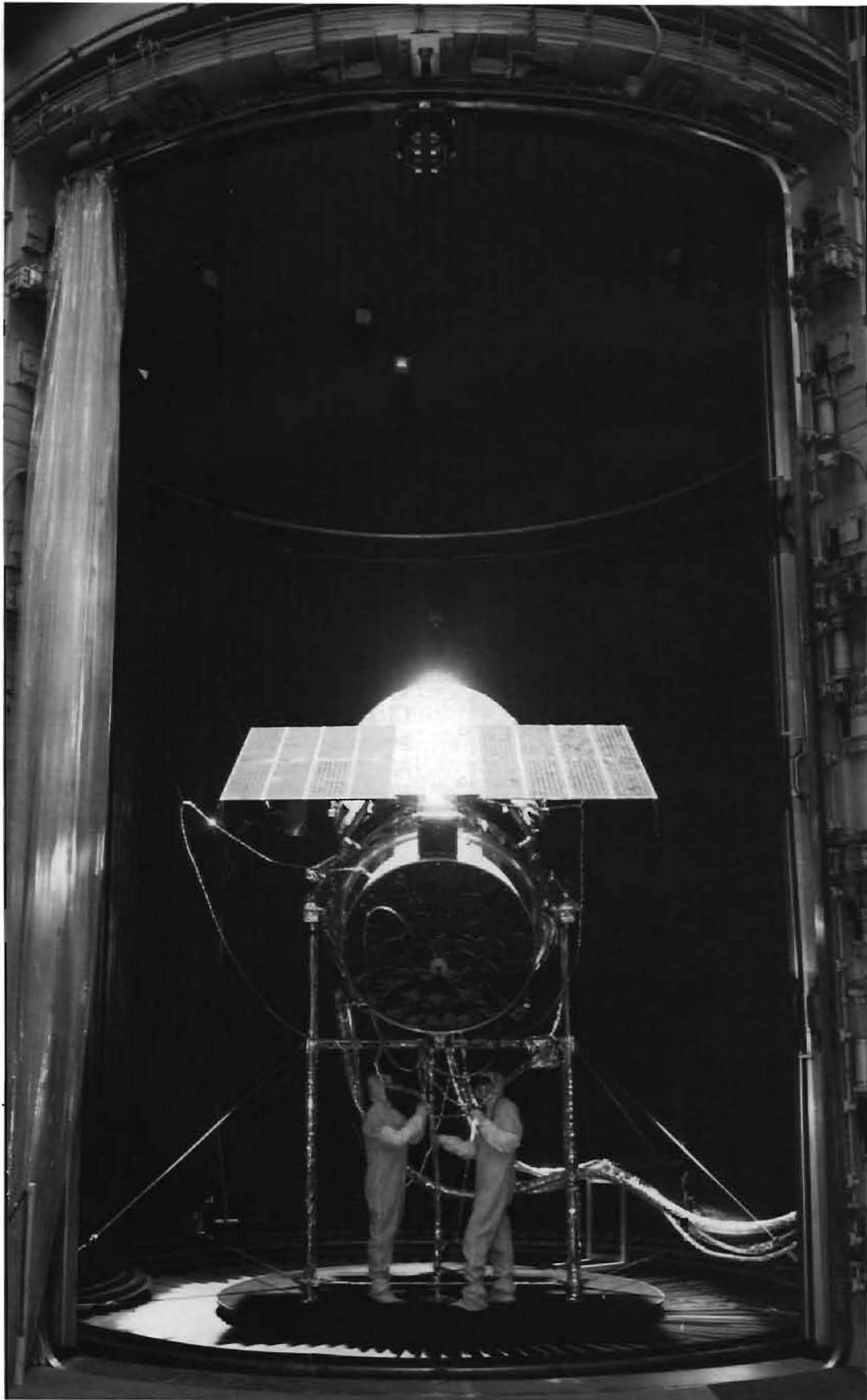
JPL has overall responsibility for Galileo, is designing and building the orbiter, and will direct the flight. NASA's Ames Research Center is responsible for development of the probe, which is being built by Hughes Aircraft Company.

The Department of Energy is providing the radioisotope thermoelectric generators that will produce electrical power for the spacecraft, and Bundesministerium fuer Forschung und Technologie (BMFT) in West Germany will provide the retropropulsion module.

Hardware fabrication for nearly all probe and orbiter subsystems was completed in 1982. The probe will be delivered to JPL in October 1983. All orbiter subsystems will be delivered to the Laboratory's Spacecraft Assembly Facility by early 1983 for assembly, integration, and testing.



In 1986, Galileo will be launched from a space shuttle and boosted toward Jupiter by a Centaur upper stage.



IRAS undergoes thermal testing in JPL's space simulator.

The Voyager mission has been given a new name to better reflect the nature of its scientific role—the Voyager Uranus/Interstellar Mission (VUIM). The two Voyager spacecraft are well beyond Saturn and en route to the outer reaches of the solar system. Except for Voyager 1's photopolarimeter and plasma-science instruments, all instruments aboard the spacecraft continue to return useful scientific information.

Both Voyagers were launched in the summer of 1977. Voyager 1 has completed its encounters with Jupiter and Saturn and is now probing the plasma and charged-particle environments of the outer solar system. The spacecraft is traveling in the general direction of the solar apex (the direction of motion of the Sun relative to nearby stars) and is expected to be the first spacecraft to exit the heliosphere, the enormous magnetic bubble surrounding the Sun and marking the outer edges of the solar wind.

Having flown by Jupiter in 1979 and Saturn in 1981, Voyager 2 is headed for a January 24, 1986 encounter with Uranus. Assuming that the spacecraft remains operative, Voyager 2's final planetary encounter, with Neptune, will occur August 24, 1989. After Neptune, Voyager 2's mission will be that of an interplanetary and possibly interstellar probe. Its course will be approximately 90 degrees from the solar apex. Both Voyager spacecraft are expected to exit the heliosphere in the 1990s.

Voyager project staffing is at the minimal level necessary to operate the spacecraft during their cruise phases and to make long-range plans for the Voyager 2 Uranus and Neptune encounters. Staffing levels will begin to increase in early 1984 as more detailed planning for the encounters begins.

INFRARED ASTRONOMICAL SATELLITE

The Infrared Astronomical Satellite (IRAS), a mission to map the entire sky in infrared wavelengths, was successfully launched into a polar orbit from Vandenberg Air Force Base on January 25, 1983. The joint international project

involves the United States, the Netherlands, and the United Kingdom.

IRAS is in a 900-kilometer (560-mile) orbit, which is high enough to avoid obscuration by Earth's atmosphere of the 57-centimeter (22.4-inch) telescope's view. The resulting sensitivity to the observed frequencies may be as much as 1,000 times greater than previous work from the ground, airplanes, or balloons or during rocket flights. Data collected over the 11-month mission will be compiled into a catalog and maps of the infrared sky.

IRAS will find many cool, dark stars as well as brighter stars shrouded by clouds of starlight-absorbing dust. The telescope will examine regions where star formation is occurring and will detect dying stars that are exhausting their nuclear fuel and ejecting large clouds of dust that absorb visible light, which is re-radiated as infrared energy. Quasars, galaxies, and the center of the Milky Way will also be studied. Scientists estimate IRAS will discover as many as 200,000 new infrared sources in the universe.

Infrared telescopes require a cold environment to achieve the sensitivity necessary for detecting faint infrared signals. IRAS carries a cryogenic system containing 475 liters (125 gallons) of liquid helium. The helium will maintain the infrared detectors in the focal plane at about 2 degrees Kelvin (–456 degrees Fahrenheit) throughout the lifetime of the mission, which in turn will depend on the rate at which the helium boils off into space.

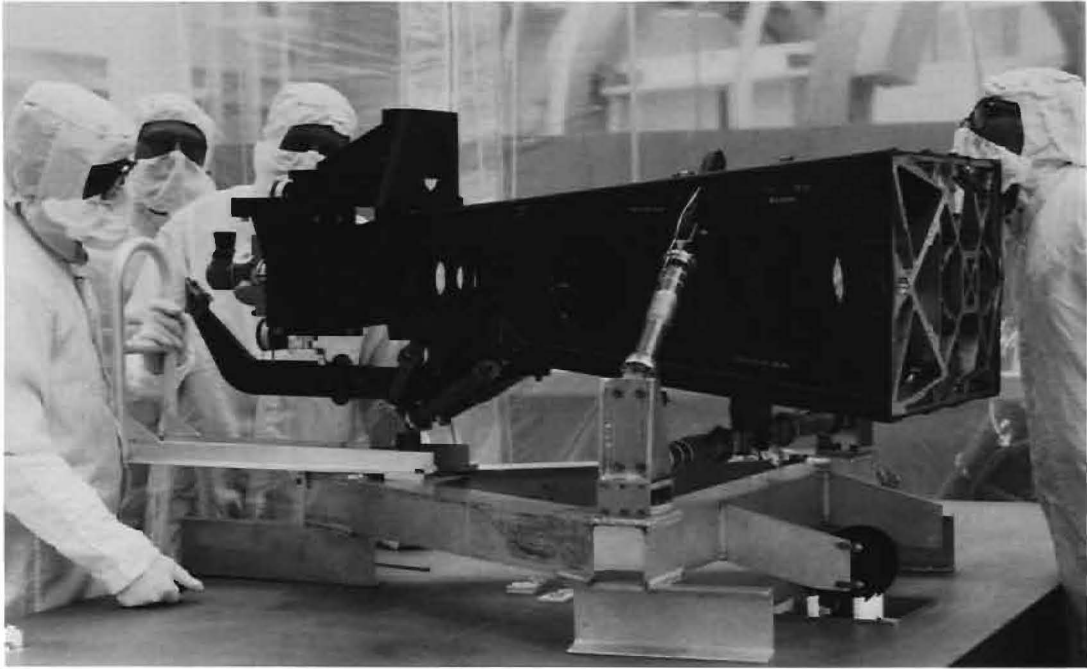
WIDE-FIELD/PLANETARY CAMERA

NASA's Space Telescope, scheduled for launch from a space shuttle in 1985, will carry the Wide-Field/Planetary Camera, which was designed and is being built by JPL and Caltech.

In conjunction with the 240-centimeter (95-inch) telescope, the camera will detect objects 100 times fainter than those visible from Earth, at about 10 times greater resolution.

Objects to be studied range in distance from planets within our own solar system to nearby stars and, beyond,

The Wide-Field/Planetary Camera will, in conjunction with NASA's Space Telescope, view objects ranging from planets in our solar system to the most distant quasars in the universe.



to galaxies and quasars in the farthest reaches of the universe. Data obtained will help answer questions about the birth and evolution of the universe.

Two JPL cameras of different focal lengths share the instrument housing and electronics. Each camera will use four charge-coupled devices (CCDs) with 800 by 800 picture elements per device to provide a composite picture of 1600 by 1600 picture elements. With a spectral response from 1200 to 12,000 angstroms, the cameras will observe and detect sources radiating in wavelengths from the ultraviolet to the near-infrared.

The wide-field camera will observe through f/12.9 optics, providing a 2.67-by-2.67-arcminute composite field of view. The planetary sensors will observe through f/30 optics, providing a 68.7-by-68.7-arcsecond composite field of view. Forty-eight filters are included.

Design and fabrication phases have been completed, and various elements of the camera are in final assembly or testing. The entire system should be fully assembled for system and environmental testing in early 1983. The instrument is scheduled for delivery to the Goddard Space Flight Center in August 1983 for integration and testing with the data system and other Space Telescope instruments.

INTERNATIONAL SOLAR POLAR MISSION

The International Solar Polar Mission (ISPM), a cooperative mission between the European Space Agency (ESA) and NASA, will investigate the polar regions of the Sun and the heliosphere outside the ecliptic plane of the solar system.

ISPM is scheduled for launch from a space shuttle in 1986. ESA is managing development and assembly of the spacecraft, which is being built by Dornier System of West Germany.

JPL is managing the American portion of the mission for NASA, which includes development of five of the scientific instruments. Flight models of the instruments were delivered to ESA in late 1982 for integration into the spacecraft. JPL is also responsible for mission design, tracking, flight operations, and data preparation and distribution. In addition, JPL is coordinating, with the Department of Energy, the development and delivery of a radioisotope thermoelectric generator to power the spacecraft.

VIKING

The Thomas A. Mutch Memorial Station (Viking Lander 1) failed to return data at the beginning of its seventh year

of operation on Mars. Efforts to correct the problem continued in early 1983.

As of November 1982, 2,300 Martian days of successful spacecraft operation had elapsed. More than three Martian years of meteorological observations had been made, enabling the development of more accurate Martian weather-pattern models by the University of Washington.

Pictures of the surface taken on September 24, 1982, show what appears to be the beginning of a dust storm in the vicinity of the station. The relative darkness of the returned images, large atmospheric pressure deviations, and significant decreases in daytime temperatures provide a strong indication of some sort of atmospheric disturbance.

During the year, 43 transmissions were received from the station, twice the number received in 1981. This provided significant new Doppler and ranging data for improving the ephemeris of Mars and for continuing relativity studies.

VENUS RADAR MAPPER

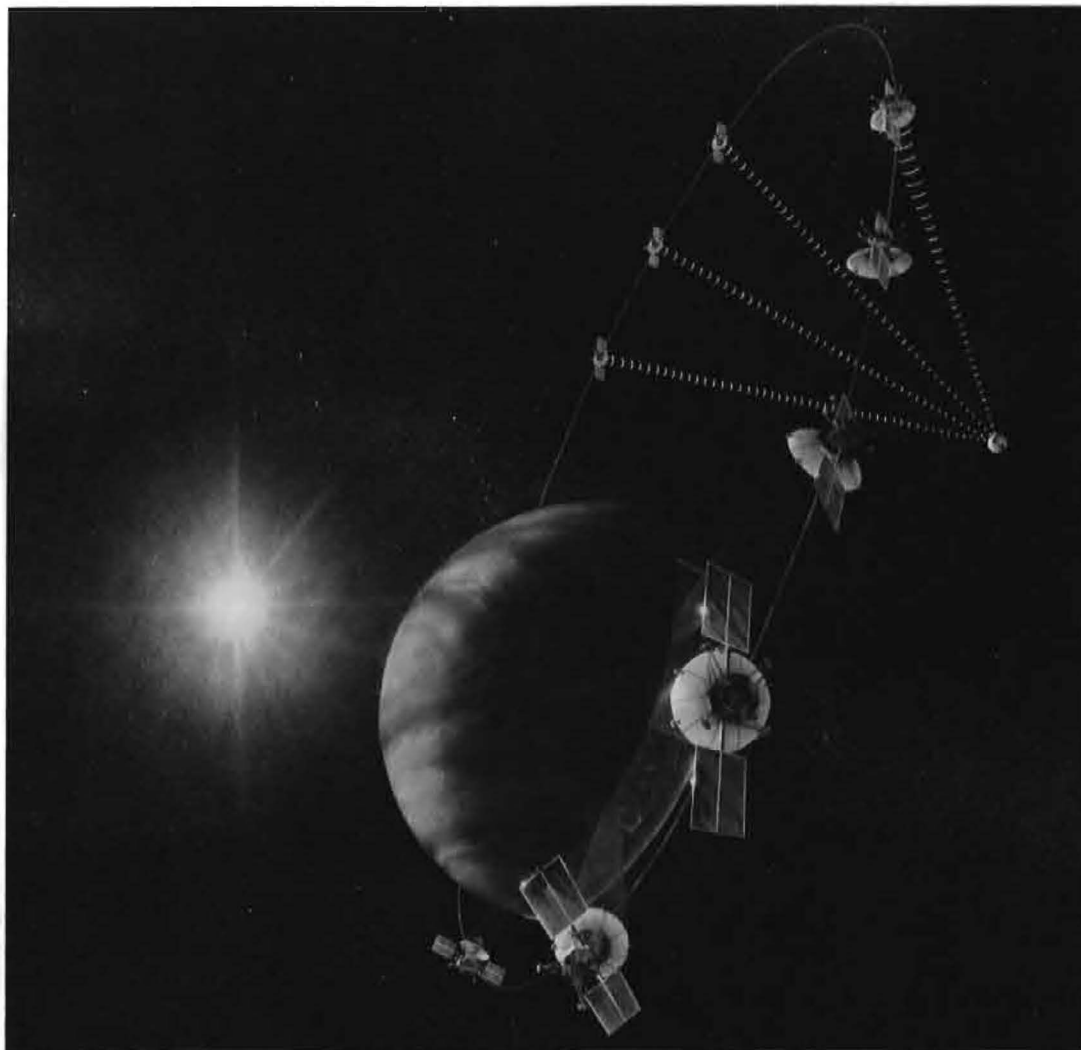
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The Venus Radar Mapper (VRM) has been approved by NASA, pending congressional authorization, for a new project start in fiscal year 1984. The spacecraft would use a synthetic aperture radar (SAR) to pierce through the thick, sulfuric-acid cloud cover of Venus to produce images of the planet's topography and geology.

While Venus has been studied by American orbiters and flyby spacecraft, and its surface examined by Russian landers, details of the planet's surface, its geology and geophysics, are yet unknown. Limited low-resolution Earth-based radar images and other data suggest a cratered surface with large volcanoes as on Mars and with mountain belts as on Earth. A study of the Venusian surface with imaging radar would provide new information on important puzzles, including the nature of the convective motions that drive plate tectonics on Earth, the importance



Photographs of the Martian surface, taken from Viking Lander 1, before, during, and after a dust storm.



Artist's concept of the Venus Radar Mapper in various stages of its elliptical orbit. The spacecraft would study Venus while closest to the planet and would return data to Earth during the remainder of its orbit.

of such tectonic processes early in Earth's history, the character of tectonics on the other inner planets, and the causes of the major evolutionary differences among the inner planets.

Launched from a space shuttle in early 1988, the spacecraft will arrive at Venus in August to begin an eight-month SAR mapping of at least 70 percent of the planet's surface at one kilometer or better resolution from a near-polar, elliptical orbit. VRM's altimeter will map the planet with a vertical resolution of 50 meters (160 feet).

MISSION PLANNING

Due to budget restrictions, continued exploration of the solar system requires the development of lower-cost spacecraft. Laboratory studies of a new class of highly adaptable spacecraft, the

Mariner Mark II, continued this year, and several possible missions to planets, satellites, comets, and asteroids were conceived. Other mission planning activities included consideration of the use of existing Earth-orbiter spacecraft designs for possible use as deep-space probes.

EXTREME ULTRAVIOLET EXPLORER

The extreme ultraviolet band is one of the last regions of the electromagnetic spectrum to be explored by astronomers. JPL is planning a mission that would send a spacecraft observatory into Earth orbit to perform an all-sky survey of extreme ultraviolet sources that radiate in wavelengths from 100 to 1000 angstroms.

The Extreme Ultraviolet Explorer (EUVE) would carry three extreme ultraviolet telescopes and a spec-

trometer. It would be launched in 1987 from a space shuttle, and it would be controlled and managed by JPL. Science instruments would be supplied by the University of California at Berkeley, where science analysis of EUVE data would be conducted.

INTERNATIONAL HALLEY WATCH

JPL and the University of Erlangen-Nürnberg in West Germany are the lead centers for the International Halley Watch (IHW), which is coordinating observations of Halley's Comet by professional and amateur astronomers around the world.

Last year was an eventful one for the IHW, highlighted by the October sighting of Halley's Comet, which will pass Earth in 1986. In January, specialists were selected to organize networks of ground-based observers in seven astronomical disciplines. In August, the International Astronomical Union voted to endorse the IHW as the world coordinator of all Halley observations. By the end of the year, discipline specialists had signed up more than 400 astronomers in 36 countries to observe different facets of the comet and its behavior.

The IHW began publication of a newsletter for professional astronomers and printed a manual for amateur Halley observers.

Other accomplishments in 1982 included agreements to establish centers at five universities for gathering Halley data. The agencies that will study Halley with spacecraft or Earth-orbiting instruments (the European Space Agency, NASA, and the space agencies of the Soviet Union and Japan) have each appointed a representative to the Halley Watch, and the IHW has been accepted as a fifth member at annual meetings held by the agencies.

SOLAR INTERNAL HELIOSPHERIC DYNAMICS MISSION

The Solar Internal Heliospheric Dynamics Mission (SIHDM) is a proposed low-cost mission designed to provide important new information on solar physics,

heliospheric structure, and the relationship between the Sun and the planets.

SIHDM would be launched in June 1988 from a space shuttle and be injected into a 13.5-month orbit of the Sun, lagging slightly behind Earth. After 27 months of flight, SIHDM would be 90 degrees behind Earth. From this unique Sun-centered orbit and offset position from Earth, SIHDM would probe the Sun's interior by measuring solar oscillations and would observe coronal events. It would gather new information that cannot be obtained using existing satellites or Earth-based measurements.

Sensitive measurements of motions of the surface of the Sun can be used to study the solar interior in much the same fashion as seismologists use motions of the Earth's surface to study its interior. Ground-based observations of solar oscillations have suggested many fascinating properties of the solar interior, including a rapidly rotating core, primordial magnetic fields, and episodes of enhanced interior mixing that lead to changes in the Sun's luminosity and hence Earth's climate.

In addition to seismology experiments, SIHDM would use scientific instruments that were to have flown on the NASA ISPM spacecraft, which was cancelled in 1981. SIHDM also would employ designs and hardware from previous NASA missions.

ORBITING RADIO INTERFEROMETRY STATIONS

Very long baseline interferometry (VLBI) has developed into an extremely powerful technique with applications in radio astronomy, geophysics, and spacecraft navigation. There are intercontinental radio interferometers operating whose station-to-station baseline is limited only by Earth's diameter. A natural extension is to put one or more VLBI receivers in orbit. This would provide longer baselines, resulting in a potential resolution of about a nanoradian—an order of magnitude higher resolution than could be achieved from ground-based VLBI. It would also provide faster and more complete VLBI mapping of celestial radio sources.

Because JPL studies have shown that the technology needed to place a VLBI station in orbit already exists, current studies are exploring various ways to begin such a mission.

LARGE DEPLOYABLE REFLECTOR

The Large Deployable Reflector (LDR) is being planned as an Earth-orbiting observatory to explore the universe in the submillimeter to far-infrared wavelengths of the spectrum, with a telescope between 10 and 30 meters (approximately 30 and 100 feet) in diameter.

As in the case of the Space Telescope, NASA would provide the LDR to a user community, which in turn would provide some of the instruments. To achieve the required precision optics and receiver sensitivity, new techniques need to be developed in several fields. These particularly include the structural, thermal, and active control of the primary reflector, the creation of new detectors for this unexplored spectral region, and the control and pointing of the telescope.

In 1982, representatives of JPL, Ames Research Center, and other concerned institutions met to determine the scientific and technical needs of the mission. As a result, experimental reflector panels will be made and tested, mission studies will continue, and work will proceed on the development of cryogenically cooled receivers.

MARINER MARK II

Mariner Mark II is a spacecraft concept for a new generation of low-cost planetary missions with a high scientific return. In the past year, the Mariner Mark II team has worked with NASA's Solar System Exploration Committee to define the scientific objectives and likely payloads for possible missions. The missions might include the delivery of atmospheric probes to the outer planets or to Saturn's moon Titan, a Saturn or Mars orbiter, rendezvous with comets or asteroids, or a cometary atmospheric probe involving a sample return to Earth.

Spacecraft and ground-system design requirements for these missions were established. The Mariner Mark II



Artist's concept of the Large Deployable Reflector being placed in orbit from a shuttle.

study team then designed a modular spacecraft that could meet all these requirements with the least possible cost for making changes from mission to mission. As conceived, the spacecraft consists of a central module that houses most of the electronic systems and subsystems, such as computer and data systems, which can be used for all missions without modification. While antenna size may vary depending on the mission, the antenna is mounted at one end of the spacecraft and will always point toward Earth. Other external modules that could be added or changed from mission to mission are the power source (solar arrays for some missions and radioisotope generators for others), a propulsion system for maneuvering the spacecraft, a pointable platform for science instruments, and a probe or Earth-return capsule.

The mission costs were estimated to be in the range of \$150 to \$300 million per mission.

LOW-COST MISSIONS

Existing satellite designs originally intended for Earth-orbital missions are being considered for use as low-cost planetary spacecraft.

If the satellites were to be used for such missions, efforts would focus on designing the best possible mission for the capability of the existing spacecraft, instead of designing a unique spacecraft to meet the needs of a mission. Reduced costs for planetary missions would be achieved in two ways: existing designs and hardware would be minimally modified for a mission, and science objectives would be focused in order to limit science instrument payloads. In addition, mission operations would be simplified to reduce demands on the spacecraft and reduce staffing for spacecraft operations.

In 1983, JPL will be studying a Mars Geoscience/Climatology Orbiter (MGCO) as the potential first mission in such a low-cost series. The MGCO would study the global surface composition, the topography, and the magnetic and gravity fields of Mars. In addition, the spacecraft would collect information on the planet's daily and seasonal cycles of carbon dioxide, water, and dust and would locate reservoirs of water and carbon dioxide and study their interaction with the atmosphere.

SCIENCE

JPL maintains a strong research and technology program in the space sciences for the support of past, present, and future missions. Continuing support for past missions is primarily in the area of data analysis, as scientists continue to reduce and analyze data from previous planetary missions. Support for present and upcoming missions such as Voyager and Galileo is in the form of project science support, science team membership, and overall science support. Future mission support is primarily for advanced studies that include possible low-cost planetary missions.

VOYAGER

Results from the Voyager 2 investigations at Saturn were published in the 29 January 1982 issue of *Science*, and findings from both Voyagers were discussed in a week-long meeting on Saturn in Tucson, Arizona, in May 1982. A book

on Saturn is to be published by the University of Arizona Press as a result of the Tucson conference. Special issues of *Icarus* and the *Journal of Geophysical Research* are presently in preparation to further disseminate findings on Saturn, primarily from Voyager observations. A special issue of the *Journal* was published to summarize Voyager findings at Jupiter.

MULTISPECTRAL MOSAICS OF THE GALILEAN SATELLITES

The multicolor images returned by the Voyager spacecraft contain far more information than can be displayed in a single color photo. Each image records brightness variations in 256 levels of gray. (Color is reconstructed from three filtered black and white images.) In addition, the Voyager cameras are sensitive to ultraviolet light beyond the range of human vision.

To analyze the varied geology and history of Jupiter's Galilean satellites, planetary scientists have combined Voyager images of each of the four moons into a data base that contains map projections covering the entire surfaces of the moons, in each of four wavelengths—ultraviolet, violet, blue, and orange. The data in each spectral band have been calibrated to produce the normal reflectance for each surface mineral and soil type.

The data bases, called multispectral mosaics, are now being used to study color variations on the moons and the relation of color to surface geology and to processes that are altering the surfaces of the satellites. Recent studies of data for Europa have shown that the ultraviolet reflectance of this satellite may be altered by magnetospheric sulfur ions from Io impacting Europa's surface—as suggested by observations from the International Ultraviolet Explorer.

ASTEROID SEARCH

The search for asteroids that cross planetary orbits yielded numerous discoveries in 1982.

An Earth-crossing asteroid, 1982 TA, was discovered on October 10–11

- 14 with the 1.2-meter (47.2-inch) Palomar Schmidt telescope.

The Apollo-class asteroid is a bright object moving in a highly elliptical orbit that crosses Earth's orbit. Its orbit is similar to that of Comet Encke, from which the asteroid may have originated.

Several Mars-crossing asteroids belonging to the Hungaria and Phocaea regions of the main asteroid belt were also discovered. The goal of the Asteroid Search Program is to determine accurate orbits for about 1,000 faint asteroids, for study from Earth-based and orbiting telescopes and for possible future spacecraft missions.

Work continues on the United Kingdom-Caltech Asteroid Survey (UKCAS), a systematic survey being carried out with plates taken using the United Kingdom 1.2-meter (47.2-inch) Schmidt telescope in Siding Spring, Australia. The orbits of 430 asteroids have been measured and computed, each one with an observing arc of at least a month.

DISCOVERY OF A GIANT X-RAY FLARE ON A DISTANT STAR

A dramatic X-ray flare—more than a thousand times greater than the biggest solar flare—was discovered by JPL investigators observing a star in the Hyades cluster, in the constellation of Taurus. The huge X-ray emission, observed during a 1982 study of data transmitted from NASA's HEAO-2 X-ray observatory in September 1980, is the largest flare ever observed from a star of the Sun's type. It caused the star to flare to 40 times its normal intensity. The magni-

tude and characteristics of this flare offer important clues to stellar evolution.

STUDIES OF PARTICLE ACCELERATION AT INTERPLANETARY COLLISIONLESS SHOCKS: PIONEERS 10 AND 11

The acceleration of particles at and near supernova shocks is thought to be fundamental to the creation of cosmic rays. Unfortunately, there is no way to test the hypothesis by making measurements at or near such shocks. However, shock waves frequently do occur in interplanetary space as a result of solar flares or fast solar plasma streams, and the unique positions of NASA's Pioneers 10 and 11 have allowed the study of details of particle acceleration where those shocks occur.

JPL and University of Chicago researchers using data from Pioneer instruments demonstrated that 0.5-to-1.8-MeV proton-flux enhancements are statistically correlated with shock waves at a 99+ percent confidence level.

Evidence was found for the acceleration of energetic protons at interplanetary shocks, both in a case-by-case examination and in statistical analyses involving several hundred shocks detected at a distance of 1 to 6 astronomical units. The efficiency of the shock acceleration process, indicated by the peak flux of energetic protons, is highest when the magnetic field upstream of the shock lies within 10 degrees of normal of the shock front. The findings suggest that the acceleration is caused by a motion of the ions parallel to the shock surface. That direction also corresponds to the direction of the interplanetary electric field, which can thereby accelerate the particles.

TELECOMMUNICATIONS SYSTEMS



Space Flight Operations Facility

Managed for NASA by JPL's Office of Telecommunications and Data Acquisition (TDA), the Deep Space Network (DSN) has performed the primary role of providing a worldwide system for communicating with spacecraft exploring the solar system. In the future, the DSN will also communicate with satellites in highly elliptical orbits and with other Earth-orbiting satellites that will not be supported by NASA's forthcoming Tracking and Data Relay Satellite

System (TDRSS). The basic elements of the DSN are three deep-space communications complexes near Goldstone, California; Madrid, Spain; and Canberra, Australia; a ground communications facility; and a control center at JPL. The Laboratory is also responsible for radio science, ground-based radar and radio astronomy, geodynamic observations, and Search for Extraterrestrial Intelligence (SETI) studies, through the TDA Office.

The DSN continued to provide general science and engineering data from both Voyager spacecraft in their cruise phases during 1982. The Network also supported spacecraft calibrations and special Voyager 2 flight data system testing in preparation for the spacecraft's 1986 Uranus encounter.

The Pioneer missions, managed by NASA's Ames Research Center, continued to return data through the DSN. Pioneer Venus assisted the March 1982 landings on Venus of the Soviet Union's Venera 13 and 14 by monitoring the planet's cloud coverage. Similar cooperation is anticipated for planned Soviet landings in 1985. In 1982, Pioneer Venus penetrated and investigated new shock and wake regions around Venus. Periodic mapping, in ultraviolet light, of the cloud tops continued to allow long-term studies of cloud features. Data on gamma-ray bursts were also collected, and gravity measurements were made to search for small-scale anomalies within the global gravitational field.

Pioneer 6, the world's oldest functioning spacecraft, exceeded 17 years of operation and continued to return solar weather data from the craft's orbit between Earth and Venus.

Pioneers 10 and 11 continued to return data on cosmic rays, solar wind plasma, and magnetic field variations, from unexplored regions of the outer solar system. Pioneer 10 set a spacecraft distance record of 28 astronomical units from Earth while approaching the orbit of Neptune. Both Pioneers 10 and 11 were used in the continuing search for gravity waves.

Helios 1, a NASA-West German solar exploration spacecraft, continued during 1982 to return scientific information on the inner solar system.

NETWORKS CONSOLIDATION PROGRAM

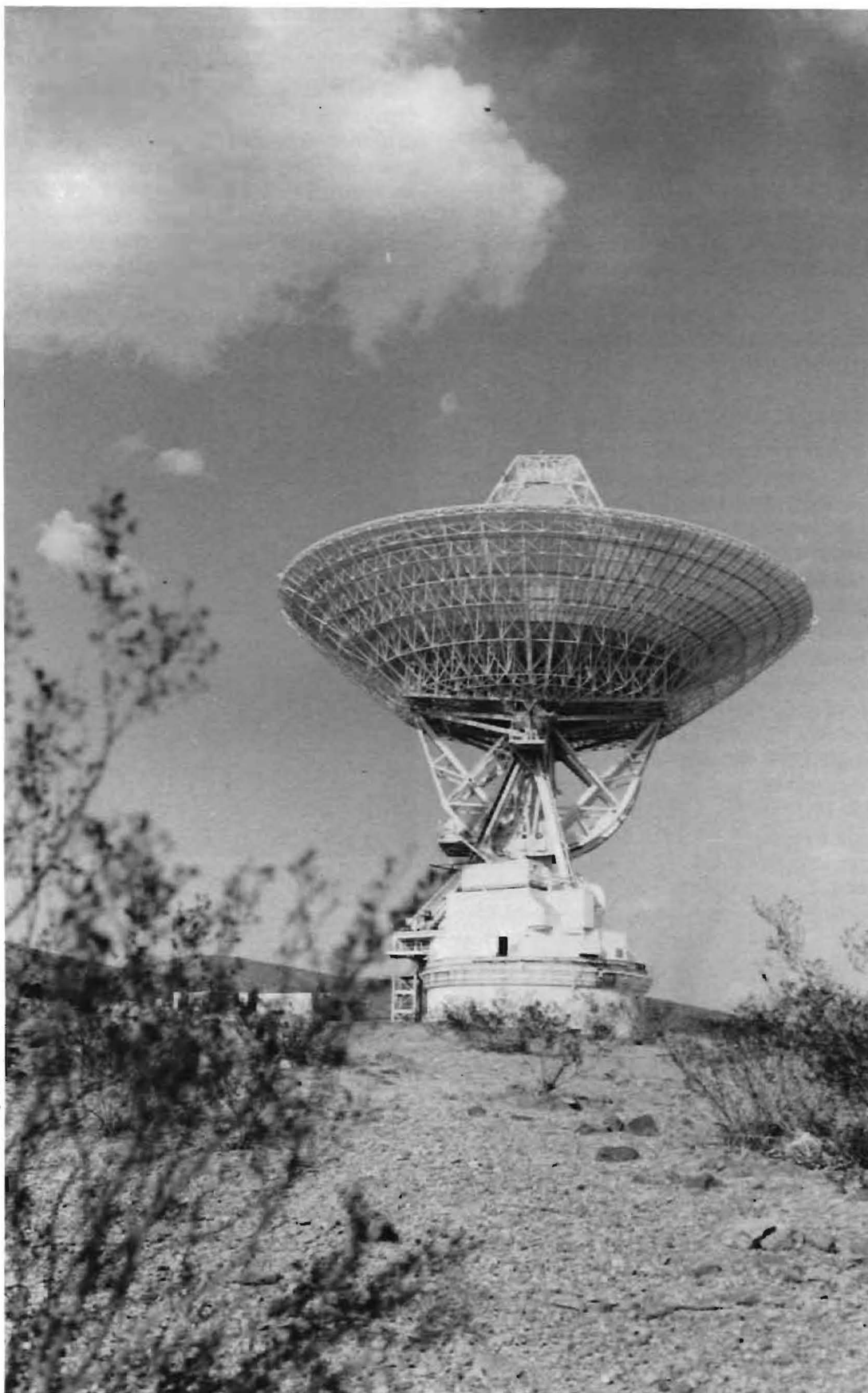
The Networks Consolidation Program (NCP) and the Mark IVA efforts to centralize control of DSN subsystems and to increase the DSN's tracking, data handling, and operations capabilities, con-

tinued in 1982 and are proceeding on schedule. This progress has been achieved against a background of increasing requirements to support additional flight projects—some of which are NASA programs and some of which are reimbursable programs from foreign space agencies. Included in these added requirements are NASA's Space Telescope, the International Solar Polar Mission, Nimbus 7, Geostationary Operational Environmental Satellites G and H, Dynamics Explorer-1, and the International Sun-Earth Explorers 1 and 2. In addition, foreign spacecraft to be supported by the DSN include: MS-T5, BS-2B, and Planet A (Japan); Giotto (European Space Agency); TV-SAT (West Germany); and TDF-1 (France).

Modifications of scope to the NCP and the Mark IVA Project reduced the number of new antennas planned for the three DSN complexes in 1982. Plans now call for a phased implementation that will provide a total of four antennas each at Goldstone and Canberra and three antennas at Madrid, to be expanded to four in time for the Voyager Neptune encounter. One 25-meter (85-foot) antenna at each complex, taken from Goddard Space Flight Center's Ground Spaceflight Tracking and Data Network, will be installed by 1985 and consolidated into the DSN by 1987.

PARKES AUSTRALIAN ARRAY FOR VOYAGER AT URANUS

Plans were made in 1982 to improve telemetry performance and provide backup in Australia for the Voyager 2 Uranus encounter. The 34-meter (111-foot) and 64-meter (210-foot) antennas at the Canberra Deep Space Communications Complex (CDSCC) will be arrayed with the Australian Commonwealth Industrial and Scientific Research Organization (CSIRO) 64-meter (210-foot) radio telescope at the Parkes Observatory. Plans call for Voyager X-band signals to be received at Parkes, reduced to baseband, and then either arrayed with CDSCC baseband by microwave link in real time or recorded and then combined within six hours of the end of the trans-



*The 64-meter
(210-foot) antenna
at JPL's Gold-
stone, California,
Deep Space Com-
munications
Complex.*

18 mission. Addition of the Parkes facility increases the imaging return from the Voyager Uranus encounter by about 20 percent if spacecraft image data compression is available. In the event of a spacecraft data system failure, image data compression may not be available and the expected picture return would be significantly reduced. In such a case, Parkes would increase the reduced image data return by nearly 50 percent.

PLANNING FOR FUTURE MISSION SUPPORT

ACTIVE MAGNETOSPHERIC PARTICLE TRACER EXPLORERS

The DSN has been developing new capabilities to support the Active Magnetospheric Particle Tracer Explorers (AMPTE), a joint international spacecraft mission involving the United States (through NASA's Goddard Space Flight Center), West Germany, and the United Kingdom. Three AMPTE spacecraft will be launched in August 1984 into a highly elliptical Earth orbit, and they will require simultaneous tracking by a single DSN complex. Two of the spacecraft will be tracked in the beamwidth of one DSN antenna. The Network will provide telemetry, command, and radio metric data to the European agencies in real time. Telecommunications and digital interfaces between project management offices in the three countries have been established and new interface testing continues in 1983.

MISSION TO COMET GIACOBINI-ZINNER

Giacobini-Zinner, discovered in 1900, is a young comet that orbits the Sun every seven years. It will return to Earth's vicinity in September 1985, about six months before Halley's Comet. NASA had considered redirecting ISEE-3, a near-Earth solar-observatory spacecraft launched in 1978, to study Halley, but found that the spacecraft's transmitter and receiver could not communicate over the distance required for a Halley encounter. Instead, ISEE-3 will be redirected to Comet Giacobini-Zinner, which will

pass Earth at less than one-half the distance of Halley.

The Giacobini-Zinner encounter will be made possible by increasing the sensitivity of the DSN's 64-meter (210-foot) antennas. By adding a second low-noise amplifier to each of the antenna apertures, signals from ISEE-3's two transmitters can be combined to provide a small but sufficiently positive signal margin at encounter. A 100-kilowatt ground-based transmitter will be used to ensure reliable communication with the spacecraft.



ADVANCED DEVELOPMENTS

DELTA VLBI NAVIGATION FOR VOYAGER AND GALILEO

A new deep-space navigation tool called differential very long baseline interferometry, or delta VLBI, is being readied for Galileo. This technique uses two DSN tracking stations on different continents to simultaneously observe the same spacecraft. A precise measurement of the difference in signal arrival times between the two stations reveals the angular position of the spacecraft.

Because this measurement can be corrupted by a number of errors, such as the clock offset between stations, the timing of the spacecraft signal arrival is followed by the observation of a quasar whose position is extremely well-known.

Comet Giacobini-Zinner will pass through the inner solar system in 1985, and NASA's International Sun-Earth Explorer-3 (ISEE-3) will encounter the comet. Communications with the spacecraft will be conducted through the Deep Space Network.

That measurement will be corrupted by the same errors; thus the errors are cancelled by comparing the two observations. The result is an extremely precise measurement of the spacecraft position with respect to the quasar.

Delta VLBI allows a delay measurement of less than one billionth of a second, which will meet the stringent Galileo accuracy requirement of 50 nanoradians, or 40 kilometers (25 miles) at Jupiter. This is five to 15 times more accurate than the conventional techniques used to guide the Voyagers, yet delta VLBI requires no uplink and only about 10 percent of the tracking time.

In January 1982, experiments were begun to validate delta VLBI at or near the accuracy required for Galileo. One such experiment was conducted using the Voyager 2 spacecraft. A score of measurements taken on both the California-Spain and California-Australia baselines showed a repeatability of 35 to 45 nanoradians. As a result, delta VLBI will soon become a prime navigational tool for Voyager throughout its cruise phase, encounter with Uranus, and travels beyond, preceding by several years the first planned operational use for Galileo.

THE TRAPPED ION FREQUENCY STANDARD

A novel, trapped mercury-ion frequency standard is currently under development for achieving improved frequency stability and operational reliability for navigation and radio science experiments. This device, based on the spectroscopic interrogation of ions confined in a radio frequency trap, is characterized by much reduced sensitivity to environmental influences, as well as by small size and simple physical structure. The accuracy to be provided may facilitate the use of spacecraft signals in the search for gravity waves.

RADIOMETERS FOR WATER VAPOR DELAY CALIBRATION

Several dual-channel microwave radiometers were constructed in 1982 in order to measure line-of-sight delay due

to water vapor in Earth's atmosphere. This delay is highly variable in both space and time; it constitutes a major error source in many of the high-accuracy radiometric systems that are either in use or under consideration at JPL. Theoretical work, as well as experiments recently completed at the Very Large Array in New Mexico, indicate that these water-vapor radiometers are indeed more accurate than any other technique in use for measuring signal delay caused by water vapor in the atmosphere.

SUPER-EFFICIENT MICROWAVE ANTENNAS

An 85-percent-efficient antenna was a major 1982 achievement in a continuing program for the development of high-performance DSN antennas. The subreflector on the new antenna is offset from the antenna aperture so that it does not interfere with incoming radio signals. The new antenna is expected to be used in applications requiring maximum gain for minimum size and/or in applications requiring the more concentrated radiation pattern at wide angles achieved by the unblocked aperture. Previous state-of-the-art Cassegrain antennas with par-



Developed in 1982, this microwave antenna, which measures 1.5 meters (5 feet) in diameter, has demonstrated unprecedented performance efficiencies.

- 20 tially blocked apertures have achieved efficiencies near 75 percent. The new antenna, a small demonstration model, is being used to confirm the theoretical electromagnetic synthesis and analysis procedures; theory indicates that a larger antenna of this type may achieve a performance efficiency of 90 percent.

22-GIGAHERTZ MASER INSTALLATION AT GOLDSTONE

A 22-gigahertz (K-band) maser was installed and operated on the 64-meter (210-foot) antenna last year at Goldstone. This frequency band will be used to determine upgrades for improved X-band receiving performance during Voyager 2's Neptune encounter, and to evaluate potential 32-gigahertz K_a-band performance. Performance comparisons will be made between the maser on the Goldstone antenna and the one installed on the Australian 64-meter (210-foot) antenna in 1981.

APPLICATIONS OF VLSI TO CHANNEL CODING

Very-large-scale integration (VLSI) of circuits is being developed for future space-communications coding systems. By using VLSI, it is possible to design very complex and efficient encoders and decoders that will also run at high speeds with low power consumption. In 1982, single-chip encoders were designed for both the NASA standard convolutional code and a Reed-Solomon code. Both these encoders are capable of processing data at rates in the megabit-per-second range, and they are both capable of encoding data in many different code parameters.

Such systems could allow individual missions to tailor coding to their requirements. In addition, hardware redundancy in the coding/decoding system to increase telecommunication-system reliability would be relatively inexpensive.

OPTICAL SPACE COMMUNICATIONS RESEARCH

Optical communications using laser beams to transfer information are

being investigated for possible use in space missions. As with microwave communications, maximum utilization of the transmitted energy is desired. In the pursuit of such energy efficiency, it was found that communication at greater than one bit per detected photon at the receiver was possible. A demonstration program was then initiated to confirm a data-transfer efficiency of 2.5 bits per detected photon. The experimental results obtained in 1982 are in excellent agreement with the theory, confirming the prediction to within 0.3 dB.

ULTRA-STABLE WIDEBAND OPTICAL FIBER SYSTEM

In 1982, an optical-fiber cable seven kilometers long was buried between the Echo and Venus DSN stations at the Goldstone, California, Deep Space Communications Complex. The cable was plowed directly into the ground at a depth of approximately five feet. Optical-fiber communications systems are being developed and demonstrated that can distribute ultra-stable and/or wideband data over long distances, up to 30 kilometers (18 miles), without repeaters. This will make it possible to consolidate DSN facilities that are scattered over a wide area into a single system controlled from a central location.

TELECOMMUNICATIONS SCIENCE

RADIO ASTRONOMY

The visible universe became more than one billion light years larger in 1982 when the most distant quasar yet was discovered through pointing information provided by a radio interferometric array at the DSN's Canberra Deep Space Communications Complex, in Australia. The Australian Parkes Observatory had produced a survey map of radio sources in the southern hemisphere. Precise coordinates of potentially interesting sources were obtained by using an array composed of the DSN's 64- and 34-meter (210- and 111-foot) antennas. These 2.3-gigahertz measurements were then used to direct optical observations. The source, PKS 2000,-330, was observed to

have a red shift of 3.78—making it the most distant object known in the universe.

SOUTHERN HEMISPHERE VERY LONG BASELINE INTERFEROMETRY

Five radio telescopes in Australia and a sixth in South Africa were synchronously operated in the first worldwide very long baseline interferometry (VLBI) experiment in the southern hemisphere, during April and May of 1982. The five Australian antennas used in the experiment were: Tidbinbilla (DSN); Parkes Observatory (Australian Commonwealth Scientific and Industrial Research Organization [CSIRO]); Fleurs (Sydney University); Hobart (University of Tasmania); and Alice Springs (Australian Landsat). The Hartebeesthoek Radio Observatory (Council for Scientific and Industrial Research [CSIR]) in South Africa completed the array.

Observations through the array provided the highest angular resolution

images of southern-hemisphere celestial radio sources yet obtained. About 30 compact sources were mapped, including Centaurus A, the nearest active galaxy; Circinus X-1, which is a flaring binary star system; and our own galactic center. In addition, vector baselines were determined between the Australian antennas, yielding the first high-precision VLBI geodesy in the southern hemisphere. The Parkes-Tidbinbilla baseline was determined with an accuracy of 10 centimeters (4 inches), while the other baseline accuracies range between 0.5 and 4 meters (1.6 and 13 feet).

MOBILE ANTENNAS

The highlight of the JPL geodynamics program in 1982 was the completion of a highly mobile transporter system for an antenna 5 meters (16 feet) in diameter, for use in obtaining geodetic measurements for the Crustal Dynamics Project. The complete system includes an

JPL's Geodynamics Program developed this mobile antenna, which has a diameter of 5 meters (16 feet), to make measurements of movements of Earth's crustal plates.



22 additional 40-foot trailer that contains the electronics and data-recording equipment necessary to operate the system. The system, along with two other mobile units used for Very Long Baseline Interferometry (VLBI), will be used to obtain geodetic measurements in the western United States and Alaska.

The geodetic measurement program is closely tied to activities at the Caltech Seismological Laboratory, the U.S. Geological Survey, and the National Oceanic and Atmospheric Administration (NOAA). NOAA's National Geodetic Survey is responsible for the operational Crustal Dynamics Project's long-term data-acquisition efforts. The mobile VLBI systems developed at JPL will be transferred to the National Geodetic Survey for operation.

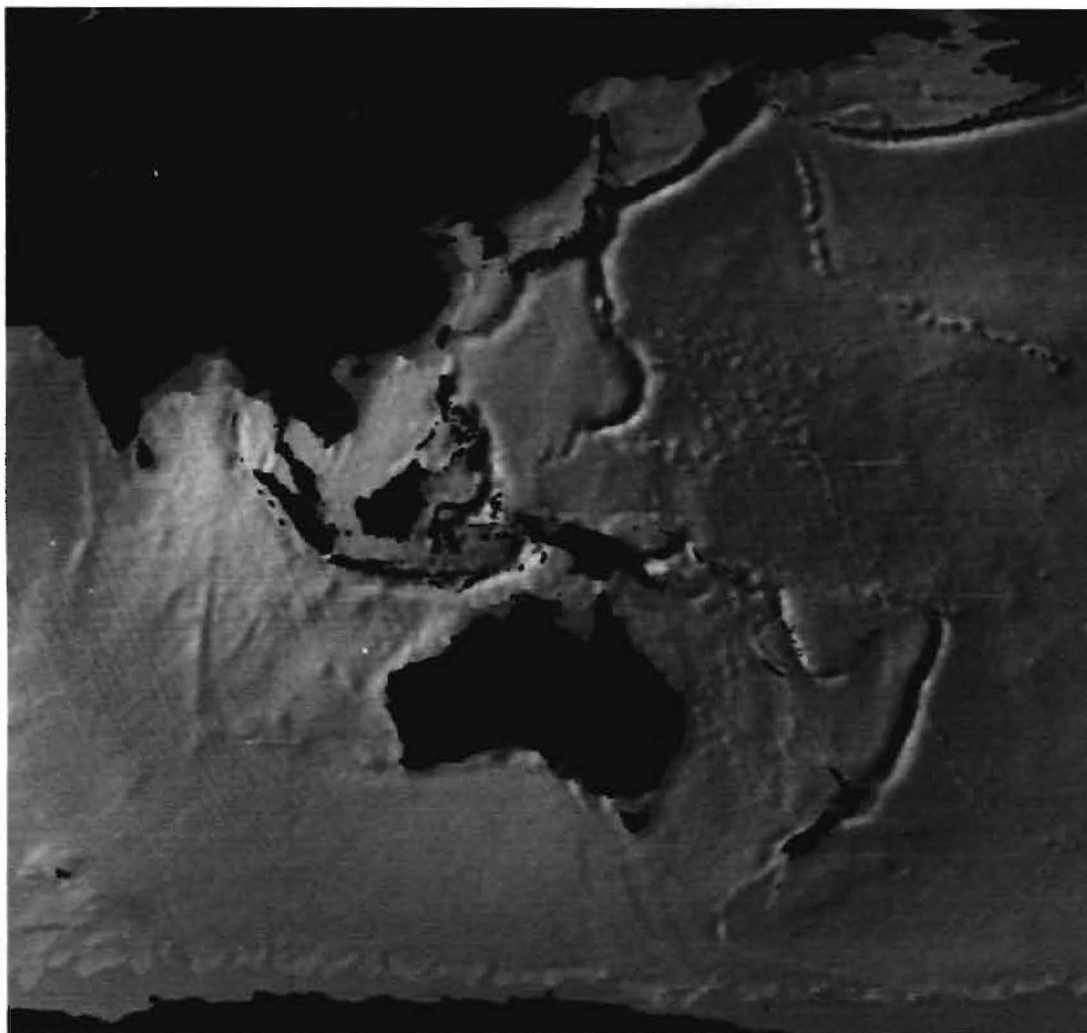
Another major development in 1982 was the application of a small mobile unit that receives signals from the satellites of the Global Positioning System. This mobile antenna, 1.5 meters (5 feet) in diameter, is called the Satellite Emission Range-Inferred Earth Surveying (SERIES) antenna and has demonstrated an accuracy comparable to that of the larger mobile systems, for a 20-kilometer (12.5-mile) baseline. Work is currently continuing, to develop this technique into a cost-effective geodetic tool. A parallel effort exists to apply the same

technique to determining orbits for Earth-orbiting missions that would require great accuracy, such as the Ocean Topography Experiment (TOPEX).

LUNAR LASER RANGING

In 1982, the JPL Lunar Laser Ranging (LLR) program made substantial improvements in the modeling of the Earth-Moon system and continued the analysis of ranges determined by transmitting laser pulses from McDonald Observatory in Texas to retroreflectors placed on the Moon's surface during the Apollo program. The ability to model the lunar orbit over the full 13-year observational span permits studies of relatively long-term variations in Earth's rotation, as well as highly accurate determinations of the Earth-Moon system's dynamics. Modeling improvements include corrections to the precession and nutation constants, which are of interest for studying Earth's interior structure. The analysis yielded improved values for many geophysical parameters, including Earth's mass (accurate to 2 parts in 10 billion) and the secular acceleration of the Moon (obtained with unprecedented accuracy at -25.1 ± 1.3 arcseconds per century, per century) due to the tidal dissipation of energy.

EARTH OBSERVATIONS



Seasat map of the Pacific

N*ew Earth-observational and Earth-orbiting experiments were either executed or planned by JPL researchers taking advantage of the new capability of NASA's space shuttle. The Solar Mesosphere Explorer, whose prime mission is to study ozone in the atmosphere, was called upon to examine the atmospheric and cli-*

matological effects of El Chichon's global volcanic cloud. Significant scientific discoveries emerged from data provided by two JPL experiments that flew on the space shuttle Columbia's second flight. Processing data from JPL's Seasat oceanographic satellite revealed new, detailed information about the ocean floor.

24 ORBITAL FLIGHT PROJECTS AND EXPERIMENTS

SOLAR MESOSPHERE EXPLORER

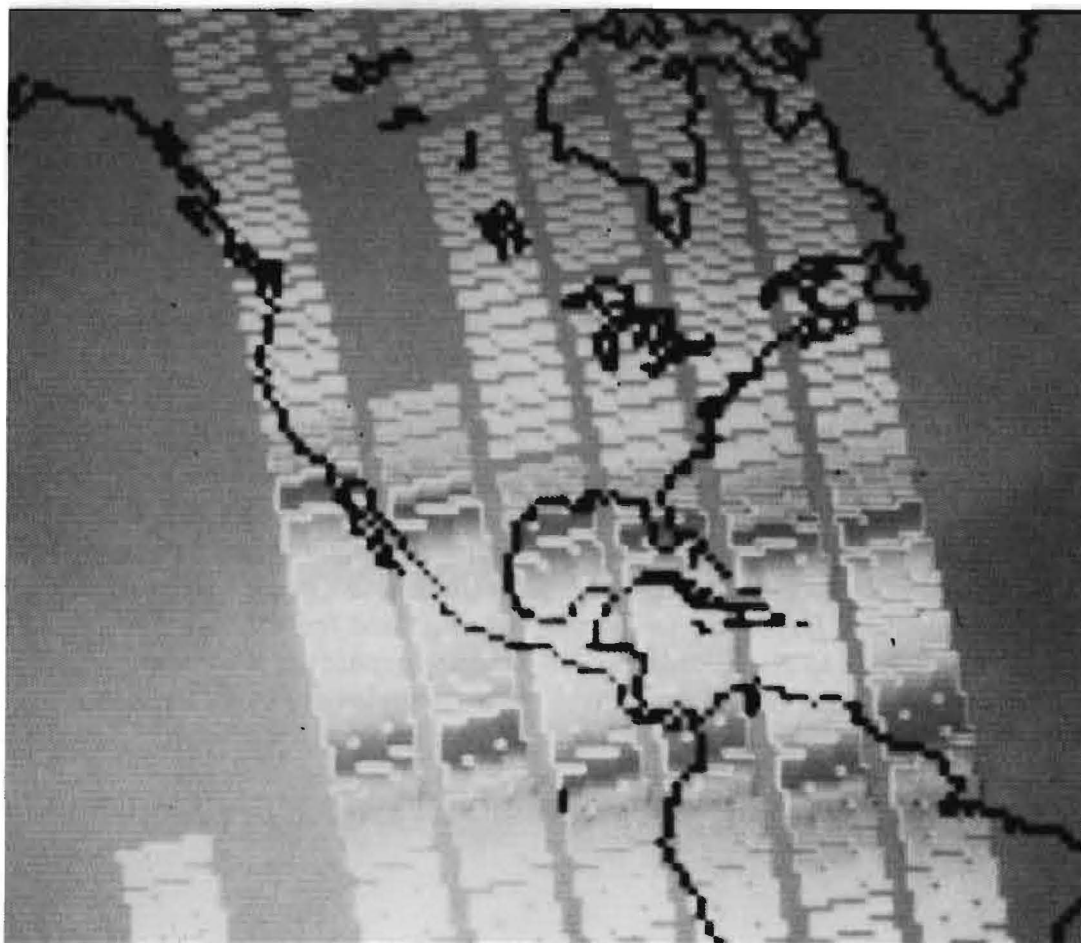
The Solar Mesosphere Explorer (SME), launched from the Western Test Range on October 6, 1981, completed its primary mission objectives in 1982 and began an extended mission, acquiring new data on a variety of mesospheric phenomena. Since April 1982, SME has studied the optical properties of the volcanic aerosol cloud that resulted from the eruption of El Chichon in Mexico. The cloud remains in the stratosphere, above the north tropical zone.

During its primary mission, SME gathered data on the nature and magnitude of changes in mesospheric ozone densities, changes that result from changes in the solar ultraviolet flux. The satellite also studied the relationship between ozone and the solar flux in general, temperature, water vapor, nitrogen dioxide, and solar proton events.

The global aerosol ring caused by El Chichon has been probed extensively by SME. Instruments continue to measure the distribution of heat emitted from the cloud particles, the scattering of visible and near-infrared light from the particles, and changes in Earth's ozone caused by the cloud.

SME measurements of the cloud showed that the cloud took six weeks to form, and that stratospheric circulation keeps most of the aerosols from moving north of 30° north latitude. SME found that the main aerosol layer was 26 kilometers (16 miles) in altitude, with some material extending as high as 36 kilometers (22 miles). The cloud reached its peak density after ten weeks, then slowly decreased in density thereafter.

The SME operations and control center is located at the University of Colorado's Laboratory for Atmospheric and Space Physics, which is staffed principally by students. SME will help test the operations of the Tracking Data Relay



El Chichon's volcanic aerosol cloud drifted through the stratosphere over Central America, as seen in this image produced from Solar Mesosphere Explorer satellite data. The cloud appears here as a bright horizontal band over Latin America.

Satellite System (TDRSS) when the first TDRSS is launched in 1983.

ATMOSPHERIC TRACE MOLECULES OBSERVED BY SPECTROSCOPY

The Atmospheric Trace Molecules Observed by Spectroscopy (ATMOS) experiment, which will fly on a space shuttle in September 1984 as part of Spacelab 3, is designed to obtain fundamental information related to the chemistry and physics of Earth's upper atmosphere. ATMOS, a high-resolution, interferometric spectrometer, measures the atmospheric absorption of solar radiation throughout the wavelength range from 2 to 6 microns, a spectral band that encompasses active transitions of all the molecular species of current importance in upper atmospheric studies. ATMOS will examine a range from the stratosphere, mesosphere, and lower thermosphere, from about 15 to 120 kilometers (9 to 75 miles) altitude. The experiment will seek to determine the detailed compositional structure of this region of the atmosphere, and its global, seasonal, and long-term variability. It will also study the way sunlight is absorbed at different levels in the atmosphere. Plans call for ATMOS to be flown on a space shuttle at approximately yearly intervals after its initial flight next year.

Flight development of ATMOS was completed in 1982, and the instrument has successfully completed tests in vibration and thermal environments. ATMOS observations must be made very rapidly and with high spectral-information content to achieve the sensitivity needed to record molecular species at volume concentrations in ratios as low as parts per trillion.

The large volume of data collected from each ATMOS flight will be processed in the ATMOS Data Analysis Facility, which has been developed at JPL expressly for processing large-volume spectroscopic data. The system, which can perform one-million-point Fourier transforms rapidly and automatically, is complemented by special-purpose radiation-transport software for the generation of synthetic spectra to

match the geometric and atmospheric conditions of the ATMOS observations. Ground tests of the instrumentation have already yielded new data based on the simultaneous high-speed measurement of several stratospheric constituents, including Freons 11, 12, and 22, and hydrochloric, hydrofluoric, and nitric acids.

OCEAN TOPOGRAPHY EXPERIMENT

A proposed mission that would map the circulation of the world's oceans from detailed altimetric measurements of the sea surface, the Ocean Topography Experiment (TOPEX) would be launched in the late 1980s. The satellite's altimeter would measure ocean-surface height variations, which can reveal details of currents, eddies, and other features of ocean circulation; these details, in turn, can reveal seafloor geologic structure. In 1982, plans were developed to add, on an optional basis, a wind-field scatterometer to the proposed satellite. The scatterometer would provide information on global ocean winds, which is required to complete the data set needed for the ocean topography experiment. Information gathered over a 3- to 5-year mission would be used to determine the global ocean's average behavior and to calculate small-scale changes and fluctuations in the ocean's circulation. Studies in 1982 indicated that an existing satellite design would satisfy TOPEX objectives.

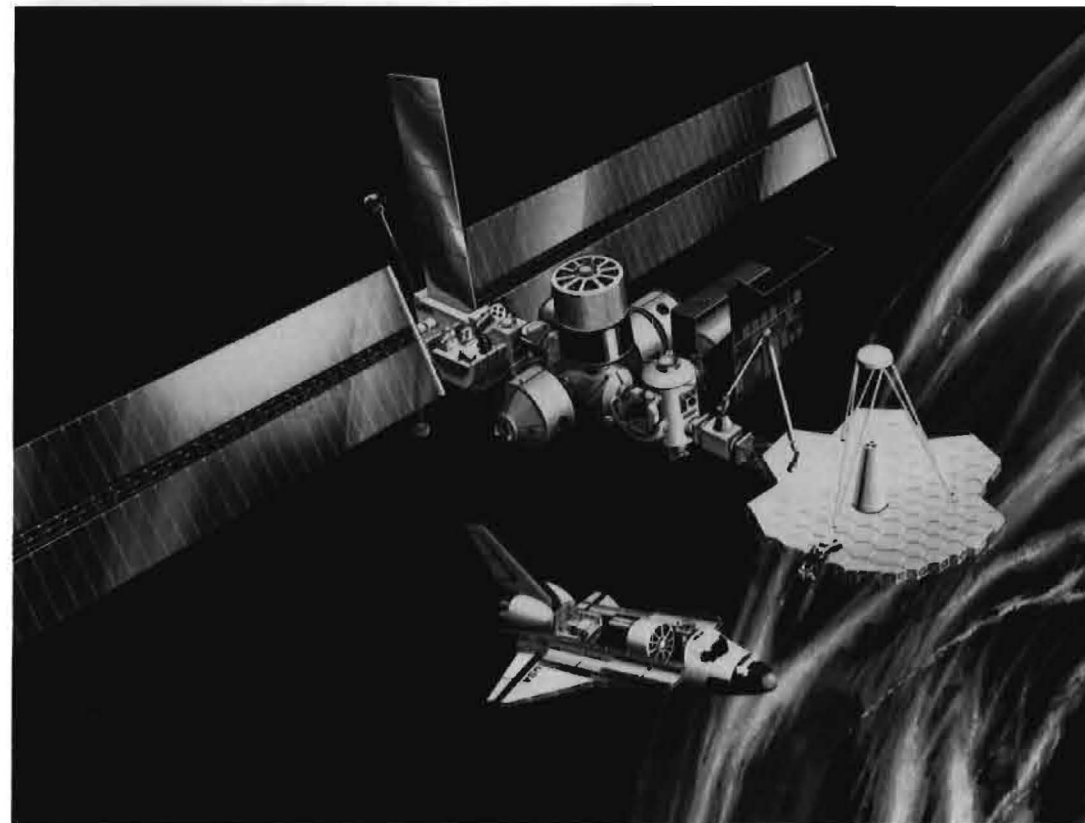
SHUTTLE IMAGING RADAR-B

The Shuttle Imaging Radar-B (SIR-B) is a follow-up experiment to SIR-A, which flew on a NASA space shuttle in 1981. SIR-B will fly on a shuttle mission scheduled for launch in the summer of 1984. It will use the JPL-developed synthetic aperture radar (SAR), which provides high-resolution images of earth and water surfaces. The radar sees through darkness, cloud cover, some vegetation, and some kinds of soil cover. SIR-B will provide data for a variety of geologic, oceanographic, and land-use studies, in disciplines including cartography, geomorphology, forest monitoring, and hydrology. Unlike previous space-borne imaging radars, SIR-B will have a

26 movable antenna that can look at targets from different angles. The experiment will provide digitally processed images for 25 hours of data acquisition, in addition to eight hours of optically processed images.

SPACE STATION

NASA has formed a Space Station Task Force to determine ways for the United States to establish a more permanent presence in space. JPL joined the task force in October with the formation of a Space Station Office within the Office of Technology and Space Program Development, and a JPL representative has been assigned to the task force. JPL has participated in defining missions and mission requirements for the space station, in the fields of space science and applications, commercial applications, and technology experiments. The Laboratory was assigned lead roles in defining information systems and the level of automation to be used on the space station. If a NASA space station program is established, JPL will continue its participation in space station planning.



Artist's concept of a design for a manned NASA space station. JPL is helping to define requirements for such a station.

INSTRUMENT DEVELOPMENT

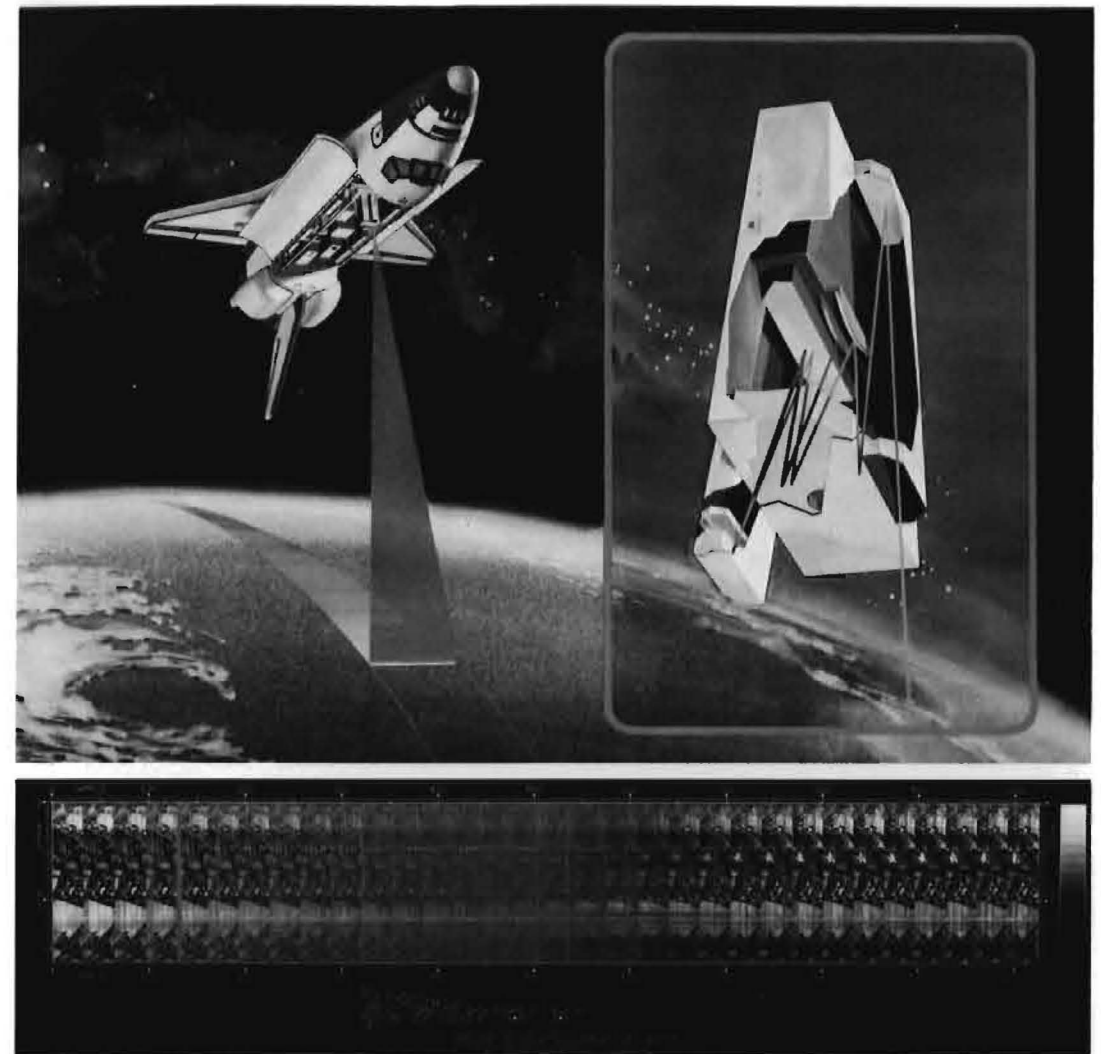
IMAGING SPECTROMETER

The Imaging Spectrometer is a remote-sensing instrument conceived by JPL as part of a NASA effort to define the next generation of Earth remote-sensing instrumentation following the Landsat program. The principal feature of the Imaging Spectrometer concept is high spectral resolution, with images acquired simultaneously in more than 100 spectral bands. This will allow direct identification of many minerals as well as assessment of vegetation types and their state of health.

The concept is based on the use of infrared- and visible-wavelength array detectors, placed at the focus of a spectrometer. Incoming radiation is first focused on a slit, then imaged again through the spectrometer onto the focal plane. One axis of the focal plane provides the cross-track spatial information. The other axis of the focal plane provides the spectral information for each element of the picture while downtrack information is provided by the spacecraft motion.

An imaging spectrometer (top) that will view Earth's surface in more than 100 spectral bands is being developed for use on a space shuttle.

This Airborne Imaging Spectrometer (AIS) test strip (bottom) shows an image taken over a Van Nuys, California, school, repeated 32 times in 10-nanometer spectral bands between 1.5 and 1.2 micrometers (left to right). The loss of detail in the center of the strip spans a 1.4-micrometer atmospheric water-absorption band. The data presented here represent one third of the total spectrum covered by the AIS.



The Shuttle Imaging Spectrometer-A will be used to evaluate the technology and experiment concepts for the next generation of systems. The development program also includes two aircraft instruments for testing the instrument concept on a smaller scale.

AIRBORNE IMAGING SPECTROMETER

Under development at JPL over the last two years, the Airborne Imaging Spectrometer (AIS) combines high spatial and spectral resolution to obtain precise identification of geologic and vegetation features. The instrument has a spatial resolution of 6 meters, a spectral resolution of 10 nanometers, and a spectral range of 1.2 to 2.4 microns. With 128 separate imaging channels, AIS pushes beyond the state of the art in both instrument development and image data recon-

struction. AIS underwent an engineering test flight over the Pico anticline area northwest of San Fernando, California, in October 1982.

MICROWAVE PRESSURE SOUNDER

Results of 1982 test flights of the Microwave Pressure Sounder (MPS) on the NASA CV-990 Airborne Laboratory showed that the instrument's short-term stability meets the design specifications and allows measurements of the required precision to be made. The experimental, two-channel, millimeter-wave radar is designed to verify a new concept for remotely measuring atmospheric pressure at Earth's surface. Measurements are taken of differential absorption through a vertical atmospheric column for comparison with theoretical values, which are calculated using simultaneous measure-

28 ments of the atmospheric profile and spectral models of oxygen and water vapor.

Variation of the measured differential absorption as a function of altitude enables surface pressure to be determined with an accuracy of 10 millibars. Changes in calibration techniques and temperature stabilization of the instrument are planned, to achieve an accuracy of one millibar.

STRATOSPHERIC BALLOON INTERCOMPARISON CAMPAIGN

JPL is a key participant in an international balloon flight campaign to conduct coordinated measurements of chemical constituents in the stratosphere. Four large balloons, each carrying instruments from countries including the United Kingdom, France, Italy, Belgium, Japan, Canada, and the United States, were launched from the National Scientific Balloon Facility in Palestine, Texas, in September 1982. JPL provided operations support, data communication, and technical coordination for the entire campaign. JPL's two-ton payload consisted of the Microwave Limb Sounder, an infrared emission interferometer, and an ozone monitor.

The goal of the flight was to obtain measurements of some 26 different molecules in the stratosphere, especially hydrochloric acid and nitric acid. The intercomparison of the measurements will assess the accuracy and precision of the measurements, test the different methods of data reduction and analysis, and test our understanding of atmospheric photochemistry through the use of computer models.

Three of the four balloons reached their planned altitudes and a majority of the instruments performed satisfactorily. The JPL gondola operated for more than 24 hours. A second set of flights is planned for mid-1983, with JPL supplying two of the four balloon gondolas. A total of nine instruments, of which six are from the United States, including two from JPL, and one each from France, the United Kingdom, and Canada, will be carried on the JPL balloons.

X-RAY CCD IMAGING SPECTROMETER

An imaging device that simultaneously provides imaging data and identifies elements by the X-ray energy they radiate has been developed at JPL. The X-ray charge-coupled device (CCD) Imaging Spectrometer represents a breakthrough for X-ray astronomy, laboratory plasma research, and X-ray microscopy. The X-ray CCD spectrometer is capable of measuring energies from 150 to 10,000 electron volts with an energy resolution or separation of 150 electron volts and a spatial resolution of 15 microns. Until its development, no single sensor existed that could both measure energy above the ultraviolet band and provide imaging data.

The imaging spectrometer photographs X-ray images by "grazing" optics that deflect and focus X-rays onto the CCD. Each X-ray liberates a small cloud of electrons within the silicon CCD chip. The number of electrons generated is proportional to the energy of the X-ray. By measuring the signal generated where the X-ray struck, the energy of the X-ray can be determined, and in turn, the element that produced the X-ray can be identified.

SCIENCE

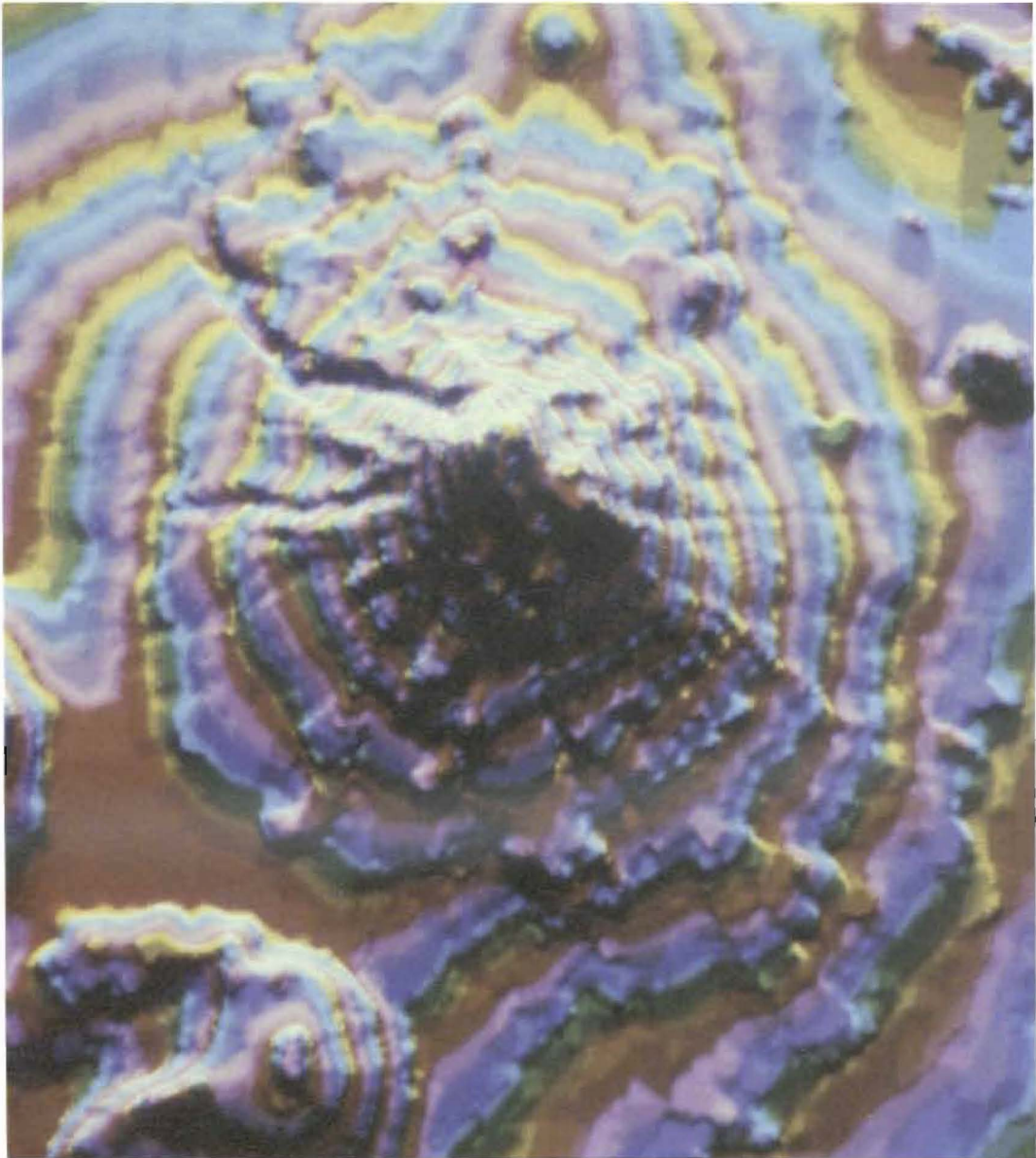
Besides its orbital flight projects and experiments, JPL has a growing program for developing research and technology applicable to Earth observations, in disciplines including oceanography, geology, and atmospheric science.

OCEANOGRAPHY

Sea-Surface Temperature Measurements. The JPL-developed Scanning Multichannel Microwave Radiometer (SMMR), launched on the Seasat and Nimbus-7 satellites in 1978, was designed to make simultaneous measurements of sea-surface temperature, wind speed, columnar water vapor, and cloud liquid water over the oceans.

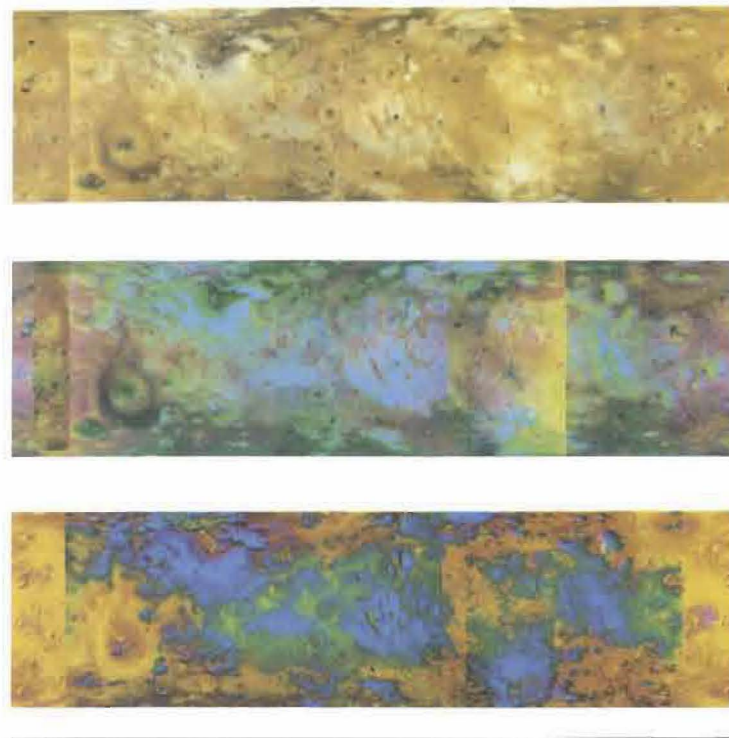
Analysis of data from this instrument has provided new information on the variability of these parameters on a global basis. Further analysis will permit

SELECTED COLOR IMAGES



Assembled from topographic measurements, this simulated radar image of Mt. Shasta was created to simulate the digital output of an orbiting radar interferometer, to determine the feasibility of gathering three-dimensional information about Earth's surface with such an instrument. The multicolored topographic contours correspond to lines of constant height above sea level.

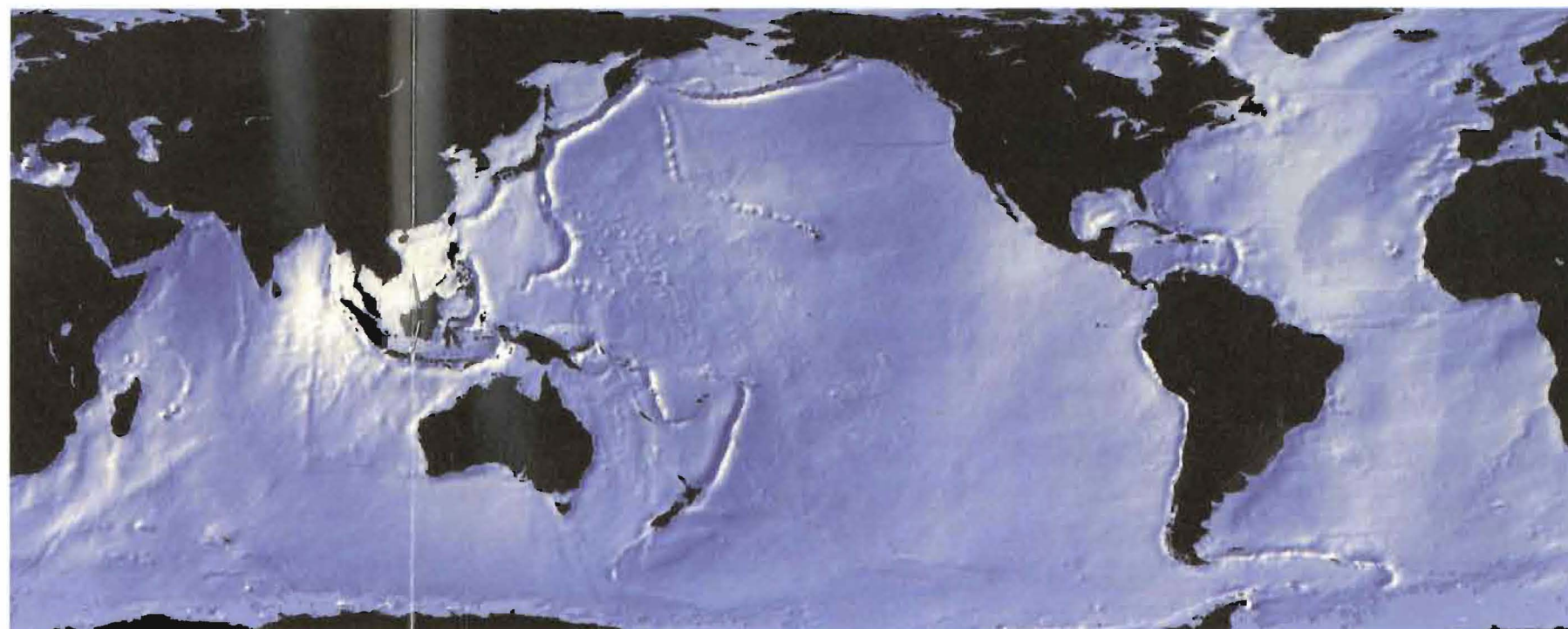
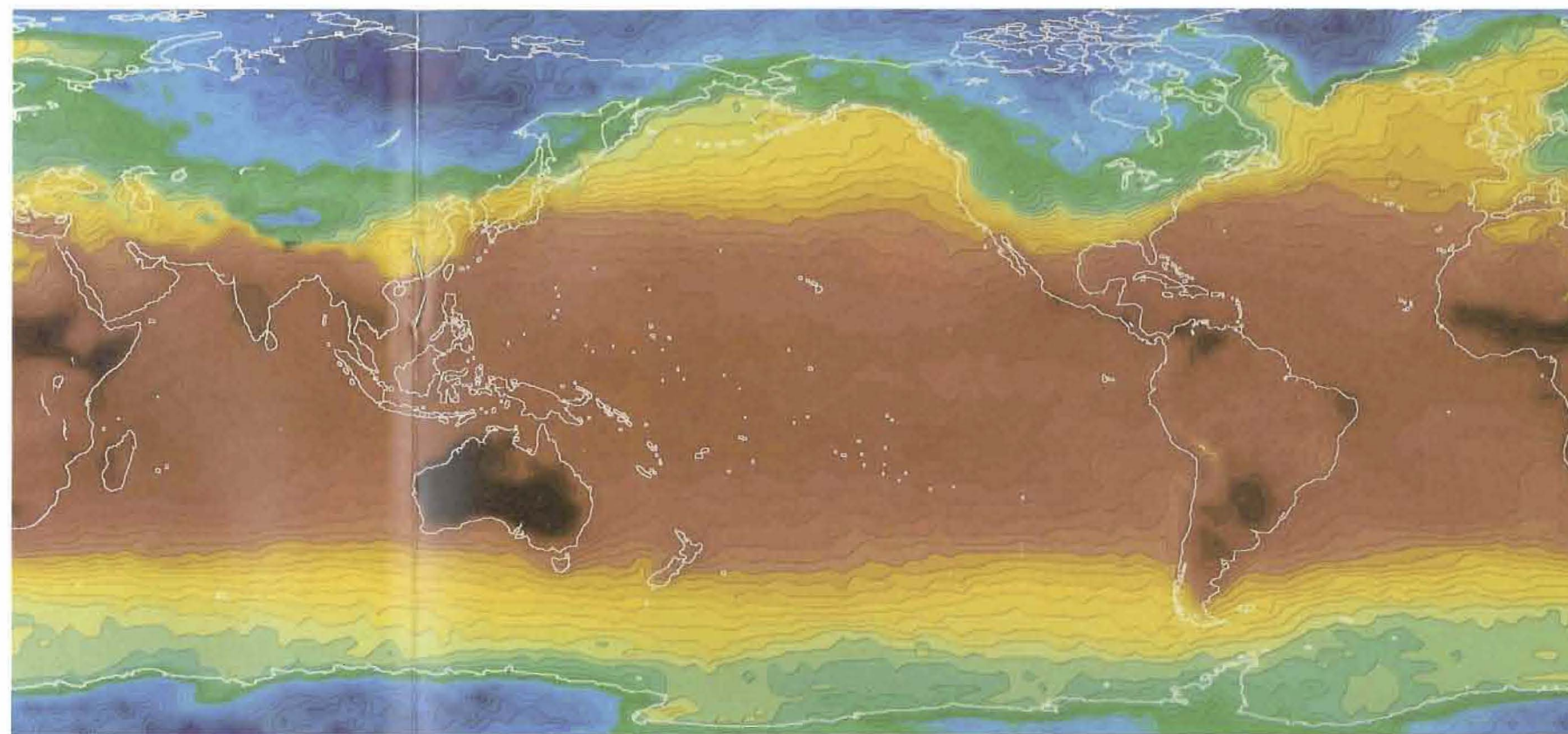
This and the following images require the use of color for interpreting scientific data. The images were produced by JPL's Image Processing Laboratory.

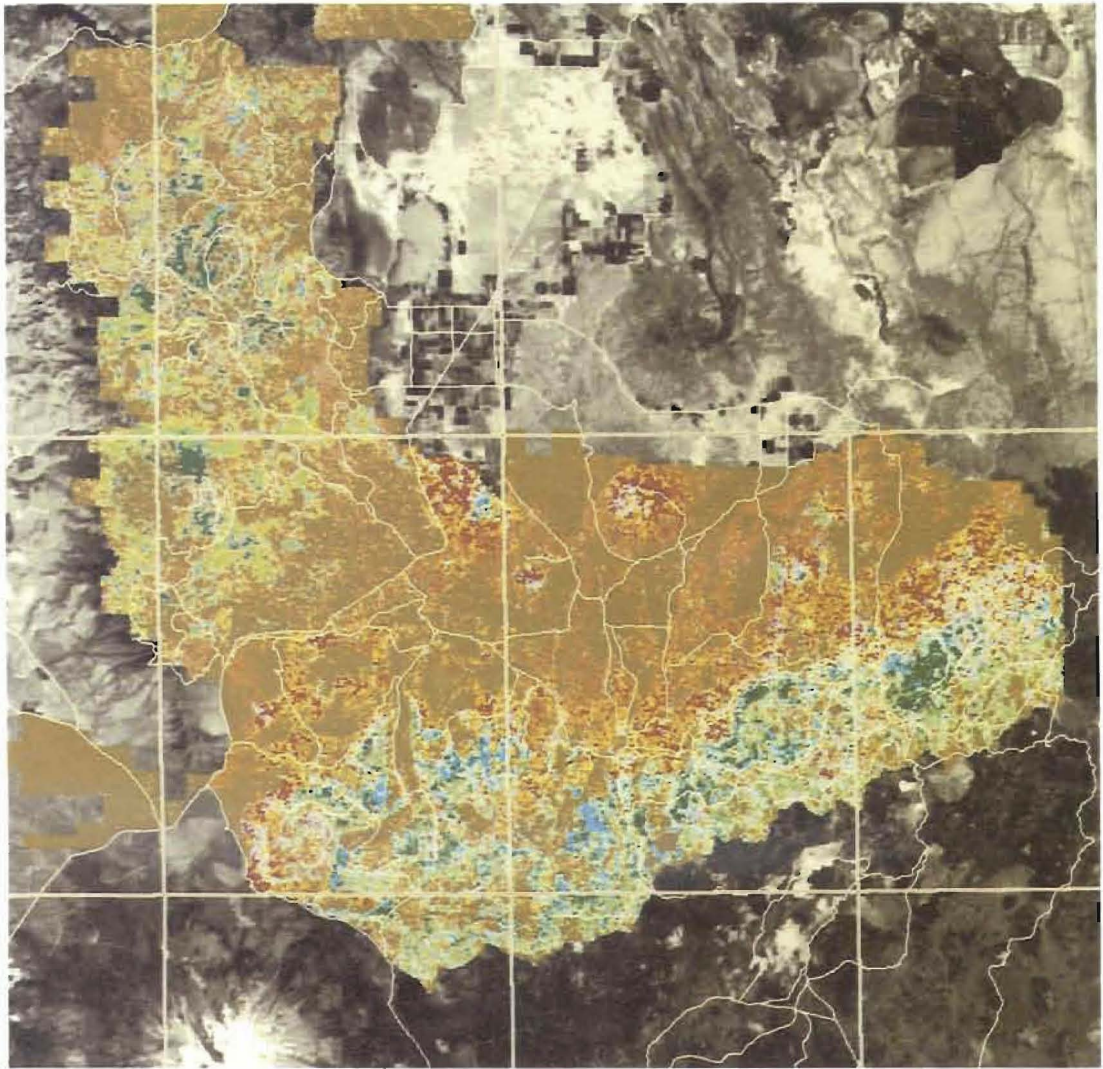


Color images can be computer-processed to enhance surface details, as shown by these three composite photos of Io (above). The top frame most closely approximates Io's true orange color, which results from the presence of large amounts of sulphur. White regions are covered by bright sulphur dioxide frost; small dark regions indicate either basalt or rapidly cooled sulphur. The lower two images were produced to enhance the very subtle brightness and color variation of the surface. (See page 13.)

This global map (upper right) represents measurements taken by high-resolution infrared sounders and microwave sounding units on U.S. weather satellites. The map shows extremely cold regions, such as Siberia, in purple, and hot regions, such as Australia, in deep red. (See page 31.)

Produced in 1982 from Seasat altimeter measurements of the ocean surface, this representation (lower right) of the global ocean floor provides a new, synoptic overview of the plate boundaries beneath the ocean. (See page 34.)





*L*andsat and digital terrain data were computer-processed to produce this map (top) showing types and densities of timber in the Goosenest district of the Klamath National Forest. Brown represents barren areas. Red indicates areas where red fir trees predominate; dark green shows dense, mixed conifer forests of large sawtimber; orange represents sparse forests of Ponderosa pine. Results of this joint study by JPL and the University of California at Santa Barbara will contribute to future use of remote sensing techniques to monitor the environment and to study global habitability. (See page 33.)

*P*ortion of Death Valley and the Panamint Mountains as seen by the Thermal Infrared Multispectral Scanner (TIMS). (See page 33.)

the design of improved instruments of this type for future applications in oceanography and climatology. SMMR data over land have also indicated the potential of microwave radiometry for long-term monitoring of large-scale features (from 30 to 100 kilometers, or approximately 20 to 60 miles) related to surface temperature, soil moisture, and vegetation. These are important as boundary conditions for models describing heat and moisture fluxes across the earth-atmosphere interface.

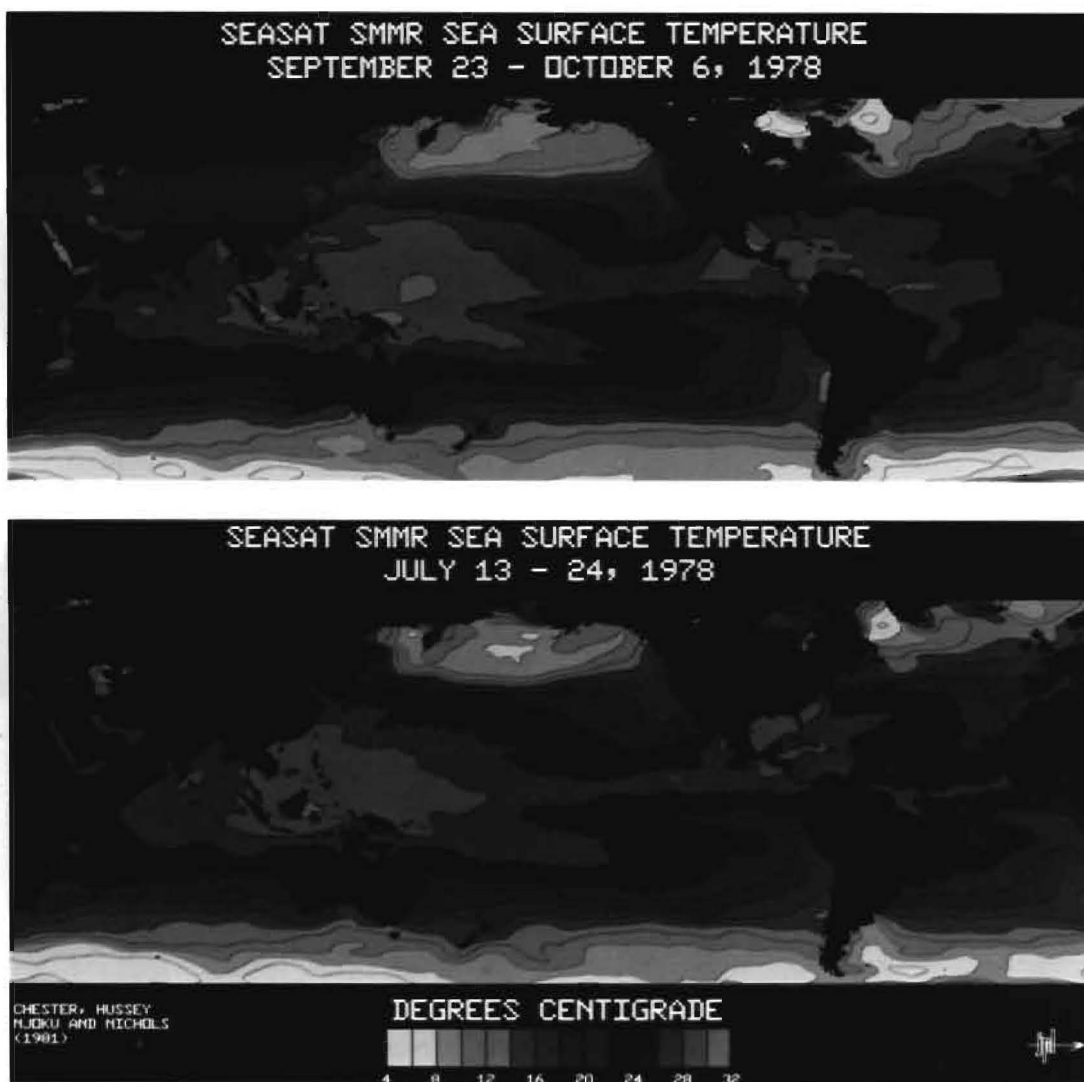
ity, at wavelengths ranging from 100 to 1,000 kilometers (approximately 60 to 600 miles). From these profiles, the wave number (or spatial frequency) spectra of the mesoscale variability in various parts of the ocean have been computed.

The resulting spectra are important indicators of the dynamics governing the mesoscale motions that in turn affect the general circulation of the oceans. The measurement of these spectra is thus an important step toward improving our ability to model the ocean's circulation.

Oceanic Mesoscale Variability from Seasat Altimetry. Analysis of the variations of sea-surface height measured by the Seasat altimeter, in repeat orbits, provided the first global, detailed spatial profiles of the ocean's mesoscale variability,

Ocean Productivity and Coastal Ocean Dynamics. Satellite imagery provides a view of ocean algal distribution not obtainable by traditional shipboard sampling and can help improve estimates of ocean productivity. Data from instru-

These two maps were produced from Seasat ocean-surface temperature measurements taken three months apart. They show average temperatures from September 23 to October 6, 1978 (top) and July 13-24, 1978 (bottom). The maps are useful in evaluating global differences and changes and compare well with similar maps generated by surface observations. (See page 31.)

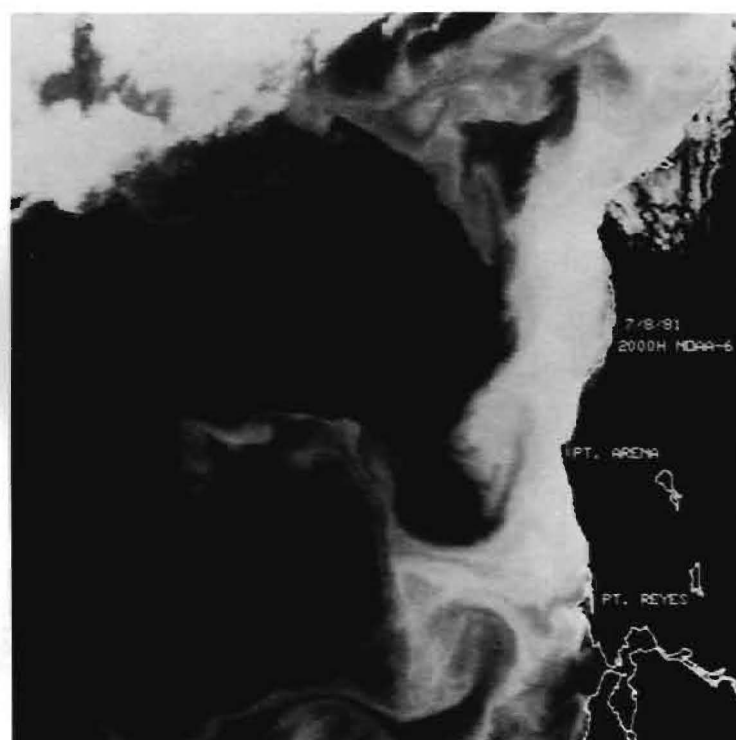
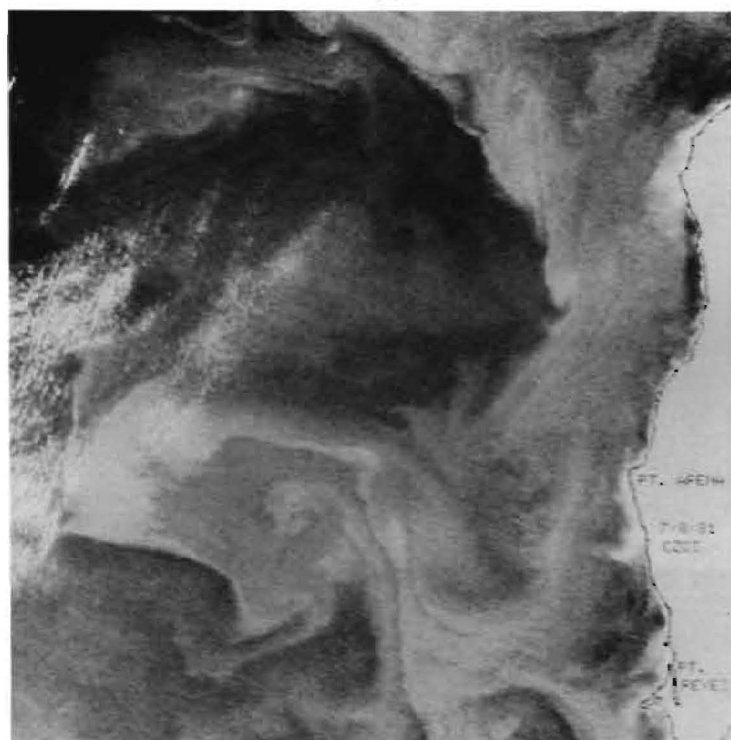


30 ments on Nimbus and National Oceanic and Atmospheric Administration satellites are being synthesized at JPL with *in situ* measurements, to determine the relationships between algal distribution and sea-surface temperature and the exchange between deep-ocean and coastal waters. While the patterns of temperature and algal distribution are generally similar, they differ significantly near shore. Synthesis of satellite and *in situ* data sets should increase our understanding of the physical dynamics of the coastal ocean and their effect on biological patterns in the sea.

Pilot Ocean Data System. The Pilot Ocean Data System (PODS) is being developed by JPL to demonstrate tech-

analysis tools. Using a terminal, an investigator can interactively examine a data-set catalog, search an on-line bibliography, browse through sample data sets, or apply assorted analysis tools to rapidly find a candidate data set and evaluate its utility for a specific application. Graphics workstations, connected to the PODS through a commercial communications network at 1200 bits per second, have been provided to investigators at several major universities and research institutions.

Available Seasat and correlative *in situ* data amount to approximately 700 megabytes on line and about 50 gigabytes on tape. Plans call for the acquisition of new data sets from several other satellite sources.



niques for the management and analysis of large amounts of oceanographic data from satellites. The complete geophysical data sets from the Seasat altimeter, scatterometer, and microwave radiometer have been compressed and stored in an on-line data system that provides rapid, selective access to data subsets selected by sensor, time, and location. A flexible, self-guided computer menu interface provides the casual user access to a growing inventory of data-management and data-

CLIMATE

Variations in Solar Irradiance. JPL's Active Cavity Radiometer Irradiance Monitor (ACRIM) experiment, on NASA's Solar Maximum Mission satellite, has monitored the variability of the Sun's irradiance (total energy output) on a nearly continuous basis since the satellite's launch in February 1980. ACRIM results have for the first time resolved solar irradiance variability on

timescales ranging from seconds to the 2.5-year duration of the experiment's record. The largest variations, occurring on timescales of days to weeks and ranging in amplitude from +0.1 to -0.25 percent about the mean, have been shown to be directly caused by the radiative effects of active regions on the Sun.

The most climatologically interesting ACRIM result is the long-term downward trend in irradiance, which had resulted in a decrease of 0.1 percent from mid-1980 to the end of 1982. This 2.5-year trend, at a rate of -0.04 percent per year, may be the beginning of an irradiance cycle related to the approximately 11-year sunspot cycle.

Climate Data Set. In 1982, a team of NASA scientists from JPL and the Goddard Space Flight Center produced the first global map of Earth's skin surface temperature, as measured by two satellite instruments. Both the High Resolution Infrared Sounder (HRIS) and the Microwave Sounding Unit (MSU) have been flying since 1979 on National Oceanic and Atmospheric Administration weather satellites. The surface temperature was derived from the 3.7-micron window channels in combination with additional microwave and infrared data from the two sounders. The combined data sets were computer-processed, using a method that removed the effects of clouds, atmosphere, and the reflection of sunlight.

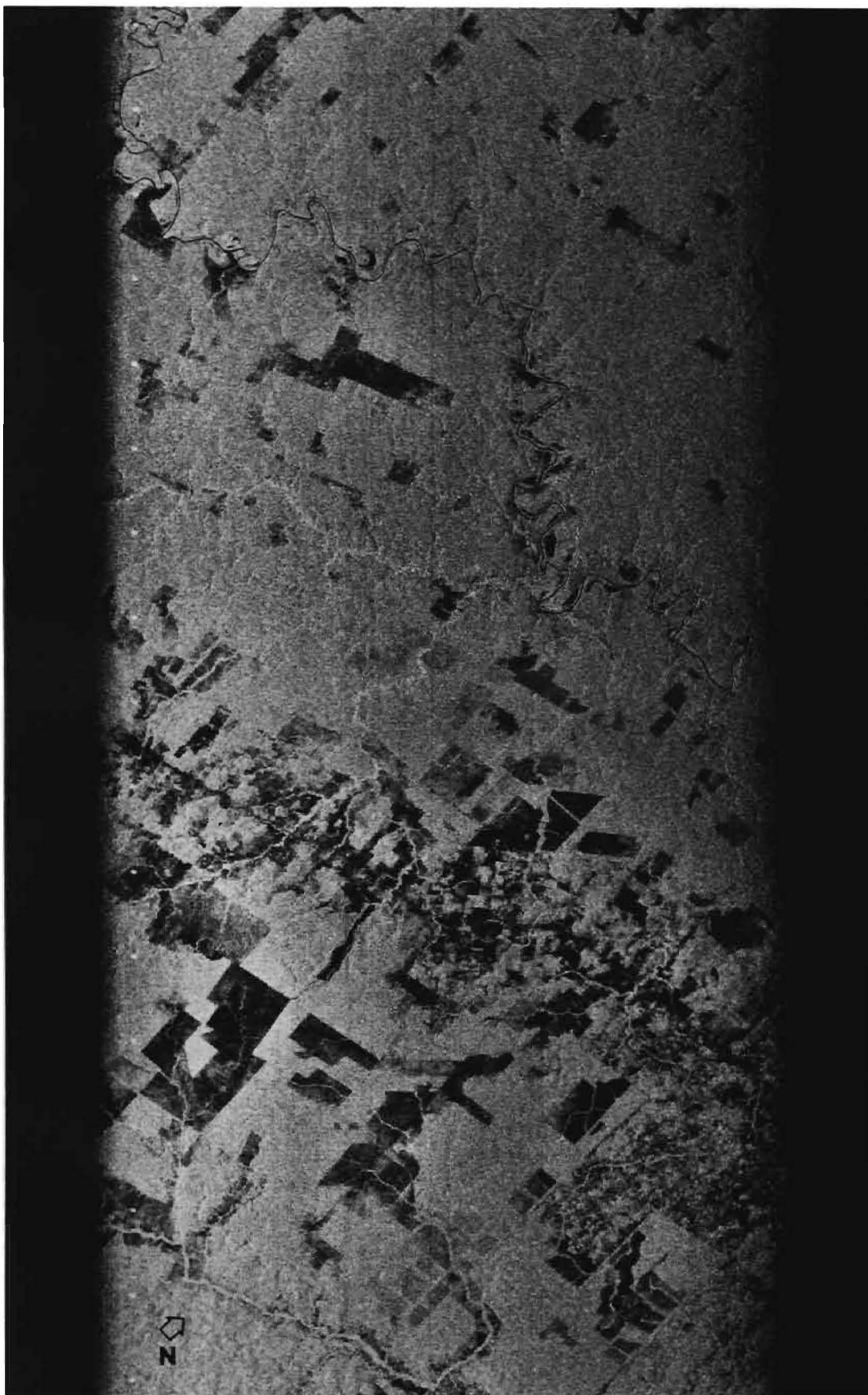
Surface-temperature data are important in weather predictions and climate studies. Since the cold polar regions cover a relatively small area of the globe, the mean surface temperature is dominated by its value in the tropics. The resulting mean temperature of the planet during January 1979 is calculated to be 287.5 degrees Kelvin (14.5 degrees Celsius or 58.2 degrees Fahrenheit). Climatologists are testing the accuracy of using surface temperature anomalies in the Pacific Ocean as potential predictors, on seasonal time scales, of weather conditions over parts of North America. In addition, day and night variations in the surface temperature can be used to study soil moisture.

Ocean-Atmosphere Interactions: Role of Biota in the Cycling of Halocarbons. The role of biology in the formation of the major constituents of the atmosphere is well accepted; in contrast, the biological interactions affecting trace atmospheric constituents are unknown. Of particular importance is the quantification of terrestrial chlorine because of its effect on the ozone layer. The work attempts to quantify the role of marine algae and bacteria, as evidence suggests they could be involved in the production of methyl chloride (a major source of stratospheric chlorine). Experiments are in progress to verify the hypotheses that the above biota are implicated in the production of methyl chloride either (1) by direct biosynthesis, (2) by producing an intermediate compound that can then be chemically converted to methyl chloride in seawater, or (3) by supplying, after death, appropriate precursor molecules for subsequent microbial transformation. The approach includes the laboratory culturing of marine algae and marine bacteria and quantitative chemical analyses utilizing gas chromatography, by using electron-capture-detector and gas-chromatography-mass-spectrometry techniques. In addition, quantitative field measurements of a marine kelp bed (Point Loma, California) known to have elevated levels of methyl chloride are being conducted. Such an understanding of the natural production of methyl chloride is required to construct a suitable atmospheric chlorine budget and to determine its contribution to atmospheric ozone destruction. This project is a joint JPL-Caltech endeavor.

Assessing Deforestation with Imaging Radar. There is a continuing increase in the amount of carbon dioxide in the atmosphere, due to the burning of fossil fuels. The total atmospheric CO₂ is less than 1 percent of the total carbon reserve held in Earth's vegetation; thus, only a small depletion of the world's vegetation could have a pronounced impact on the global carbon balance.

Imaging radar, capable of obtaining high-resolution imagery of Earth's surface without respect to weather or

Satellite images show the population distribution of algal phytoplankton (left), compared with ocean-surface temperatures (right) in California coastal waters. Light areas in the left image represent phytoplankton. Light areas in the right image correspond to colder temperatures (Bright areas are clouds.)



This Shuttle Imaging Radar-A image shows deforestation in northeastern Brazil. The imaging radar's ability to see through cloud cover makes it well-suited for monitoring the rate of deforestation of the world's rainforests. Dark areas represent rainforest while light areas show deforestation.

lighting conditions, is providing useful data for global climate models. JPL's Shuttle Imaging Radar-A (SIR-A) provided data for 10,000,000 square miles, including a large area of the world's tropical rainforests—areas that may be vital to the global carbon cycle. When forests are destroyed, not only is a natural carbon sink removed, but the burning of the forest becomes an additional source of CO₂.

Researchers are using radar imaging data to determine the relationship between the radar image tone and texture and the interpretation of these data to detect deforestation in tropical, temperate, and boreal forests.

GLOBAL HABITABILITY

JPL is participating in the planning of a new NASA program on global habitability; this program is intended to be a major research effort to understand the global physical, chemical, and biological changes that can affect the habitability of Earth. It will make extensive use of satellite observations as well as of NASA's highly developed information-processing capability. The program will involve observations of the land, the ocean, and the atmosphere, as well as the interaction of all three.

GEOLOGY

Thermal Infrared Multispectral Scanner. A new airborne Thermal Infrared Multispectral Scanner (TIMS) that identifies a greater variety of rocks, soils, and vegetation than previous infrared scanners was completed by Daedalus Enterprises for JPL and NASA. In 1982, TIMS was installed in a Lear Jet at NASA's National Space Technology Laboratories, Bay St. Louis, Mississippi, and the first test flights of the instrument were made over previously studied sites at Goldfield and Cuprite, Nevada; Tintic, Utah; and Death Valley, California. Characteristic spectra of rocks and soils in the infrared between 8 and 12 microns allow separation of silicates from nonsilicates and some discrimination between different silicates. TIMS measures emissions in the infrared bands of 8.1 to 8.5; 8.5 to 8.9;

8.9 to 9.3; 9.5 to 10.1; 10.2 to 10.9; and 11.2 to 11.7 microns.

At the Goldfield and Cuprite mining districts, silicified altered rocks stood out clearly in color images made from TIMS data. In addition, the instrument identified basalts, opalized rocks, argillized rocks, carbonate rocks, vegetation, younger versus older alluvium, and alluvial material from different sources. False colors used to identify the various materials in the TIMS images from each of the sites could be related to false colors in previous images of Tintic; spectrally flat vegetation and carbonates were green, clays blue to purple, and silica-rich rocks showed as red, orange, and pink.

Future plans for the instrument include further work in noise reduction, followed by complete calibration, characterization, and documentation. It will then become a NASA aircraft facility instrument, available for research by approved investigators. Research continues on development of a shuttle-based TIMS.

Shuttle Multispectral Infrared Radiometer. A previously unprospected area that is potentially rich in ore deposits was located in a remote Mexican desert by JPL's Shuttle Multispectral Infrared Radiometer (SMIRR), which was carried on the space shuttle Columbia in November 1981. The area, which was subjected to magma-heated steam and hot water tens of millions of years ago, was identified through SMIRR data by the presence of a group of minerals: kaolinite, alunite, and iron oxides. A team of JPL and Mexican government scientists investigated the area in 1982 and verified that the area is a prospective mineral deposit. The finding marks the first time that a group of minerals typical of metal-rich areas has been discovered from space. Initial geochemical analysis on samples collected at the site show high values for molybdenum and silver, showing that further detailed studies are warranted to prove out this promising prospect.

NASA/Geosat Nonrenewable Resources Study. The joint NASA/Geosat nonrenewable resources test case project was

34 completed in 1982. This marks the culmination of a four-year effort that involved the coordinated efforts of JPL scientists and the representatives of more than 30 mineral and petroleum exploration companies. The project represents the most thorough analysis to date of remote-sensing technology for geologic applications and nonrenewable-resource exploration.

To evaluate present capabilities and the future needs and potential of remote sensing, the study focused on three commodities: copper, uranium, and petroleum at eight typical deposits in the United States.

Data from several NASA satellite instruments were analyzed, as well as aerial photography, ground spectral reflectance, and geochemical measurements. Data from the Landsat-4 Thematic Mapper (obtained using NASA's airborne simulator) provided the most useful geologic information at all eight sites. At the copper sites, alteration zones that were related to mineralization were mappable. Recognition of alteration can be used to target and evaluate potential ore deposits in poorly explored regions of the world. The uranium investigation demonstrated the capability of more accurately mapping the bleached and unbleached surface rocks associated with uranium deposits underneath. The petroleum investigation demonstrated the improved capability for mapping geologic rock types and vegetation types over heavily vegetated areas. The two capabilities provide information crucial to inferring subsurface structures that may trap hydrocarbons.

Results of the project will assist NASA in establishing the requirements and measurement characteristics of future space-sensor systems. Industry benefitted by obtaining greater insight into the potential utility of remote-

sensing technology for resource evaluation and exploration.

Viewing the Ocean Floor from Space.

Satellite altimeter readings of the ocean surface have been processed to create a topographic map of the global ocean floor. The map shows details on the ocean surface that reflect previously unknown features of the ocean floor, especially in the poorly surveyed southern oceans. One example is the Louisville Ridge southeast of New Zealand, which existing bathymetric charts show as a discontinuous chain of seamounts. With the detection of new seamounts, the ridge is now confirmed to be a continuous chain. Northeast of the Louisville Ridge is a large plateau nearly the size of California that appears much larger than previously suspected.

For known features, the magnitude of the perturbation in the ocean surface provides additional geologic information about the underlying feature. For example, a large "seamount province" southeast of Japan is now known to be composed of seamounts much younger than the crustal material underneath, because of the relatively high ocean-surface response. This means that the underlying crust is quite rigid, an effect that can only occur when the crust is old.

The volcanic Hawaiian Islands and Emperor Seamount Chain dominate the center of the Pacific. These volcanoes are created as the Pacific plate moves northwestward over a hot spot in the mantle beneath Hawaii; new volcanoes are continually being created as older ones to the northwest become extinct. This chain of seamounts provides a record of the past movement of the Pacific plate. The bend in the chain marks a major shift in the direction of plate motion that occurred about 40 million years ago.

DEFENSE PROGRAMS



LOCKHEED MISSILES & SPACE COMPANY INC.

Remotely Piloted Vehicle

Established in 1981, JPL's new Defense Programs Office is actively pursuing work with the U.S. Air Force, Army, Navy, and Defense Advanced Research Projects Agency (DARPA). In 1982, a JPL Liaison Office was established at the U.S. Air Force Space Division in El Segundo, California. The office furnishes an on-site presence for

developing an institutional relationship between JPL and the Space Division.

Currently funded efforts under the Defense Programs Office range from large projects, for which JPL has full project-management accountability, to smaller, advanced technology tasks that draw from the broad technology base at JPL.

Work was completed on the first phase of the Autonomous Spacecraft Program for the Air Force Space Division. The aim of this phase was to transfer to defense-satellite use the design and operation practices used for planetary spacecraft. Planetary spacecraft require autonomous features because of long two-way communication times, and JPL's development of those features has resulted in a unique set of skills that the Laboratory can directly apply to national-defense needs.

During 1982, a 550-page handbook was produced, documenting JPL's experience in designing and operating planetary spacecraft with autonomous features. The handbook is intended to aid in the transfer of methodology experience from JPL to the Air Force and industry. It addresses both spacecraft system and subsystem level implementations, and it provides detailed examples of proposed and flight-proven autonomous control algorithms. The handbook also contains a historical summary of selected flight program experience.

The second phase of this effort began in late 1982, and will involve, over three years, the design and ground demonstration of an Autonomous Redundancy and Maintenance Management Subsystem (ARMMS). The subsystem is an add-on feature that will provide on-board autonomous control of power, attitude control, and other subsystems in existing defense-satellite designs.

REMOTELY PILOTED VEHICLE PROJECT

JPL continues to provide engineering support to the U.S. Army's Remotely Piloted Vehicle (RPV) project. The remotely controlled aircraft is designed to detect and identify targets behind enemy lines and to provide other intelligence for battlefield commanders. Since 1977, JPL has provided general system engineering, technical review,

and evaluation of the full-scale engineering program. The support includes technical evaluations and recommendations to the Army project manager and evaluations of the prime contractor, Lockheed Missiles and Space Company, Sunnyvale, California.

The RPV system consists of the pilotless vehicle (which carries an electro-optical sensor package), a ground control station, a truck-mounted launcher, a truck-mounted recovery subsystem, and associated ground support equipment.

JPL is contributing to the vehicle's electro-optical systems, communications, navigation, computer software systems, and mission operations and control systems technology. Engineering support is being provided in systems integration, performance analysis, mechanical and hydraulics design, and test engineering.

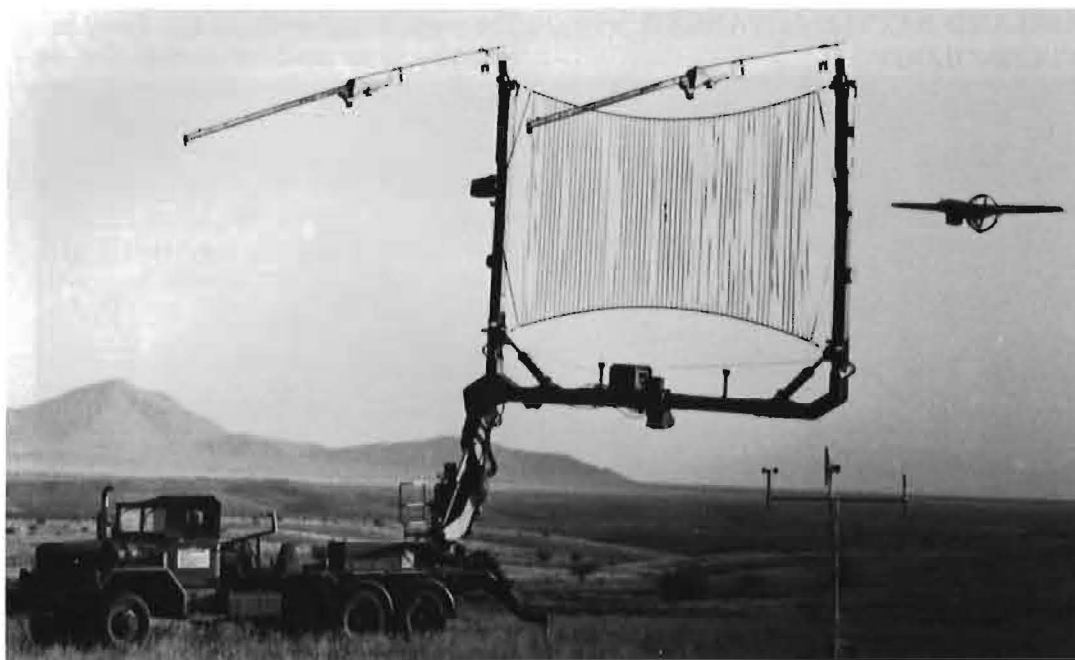
TALON GOLD

JPL performed work on the project-definition phase of Talon Gold, an experimental program for the development of acquisition, tracking, and pointing technology. Work included an independent cost assessment of the program as it is currently conceived and a determination of mechanisms to control Talon Gold project implementation and operations in the post-definition phase.

ADVANCED MATERIAL TECHNOLOGY DEVELOPMENT PROJECT

The U.S. Army Tank-Automotive Command is sponsoring a project at JPL to apply the Laboratory's expertise in advanced materials and weight-minimizing design concepts to lightweight, armored combat vehicles. Armor and structural weight are a critical issue in the new generation of armored combat vehicles. These machines must be transportable by air to achieve the required strategic mobility. At the same time, they must continue to offer maximum crew protection and durability.

Boosted into flight from a truck-mounted launcher, the Remotely Piloted Vehicle returns and is captured in a portable recovery net.



AIRLAND BATTLE ADVANCED TECHNOLOGY

The Airland Battle Advanced Technology project was established at JPL in 1982 in support of the Army's New Thrusts Program, which is conducted within the Materiel Development and Readiness Command (DARCOM) under management of DARCOM headquarters. The Army's New Thrusts Program was initiated to exploit those areas where the United States holds key technological advantages. The program will be carried out and augmented by Army research and development funding in key technologies and systems, by greater utilization of commercial equipment, and by increased system attention to battle-field operations. JPL will assist DARCOM headquarters with the definition, planning, implementation, and management of the New Thrusts Program. Among the tasks completed by JPL in 1982 was a technology assessment of electro-optical sensor options for remote surveillance, applying JPL's technical expertise to one of the Army's thrust areas.

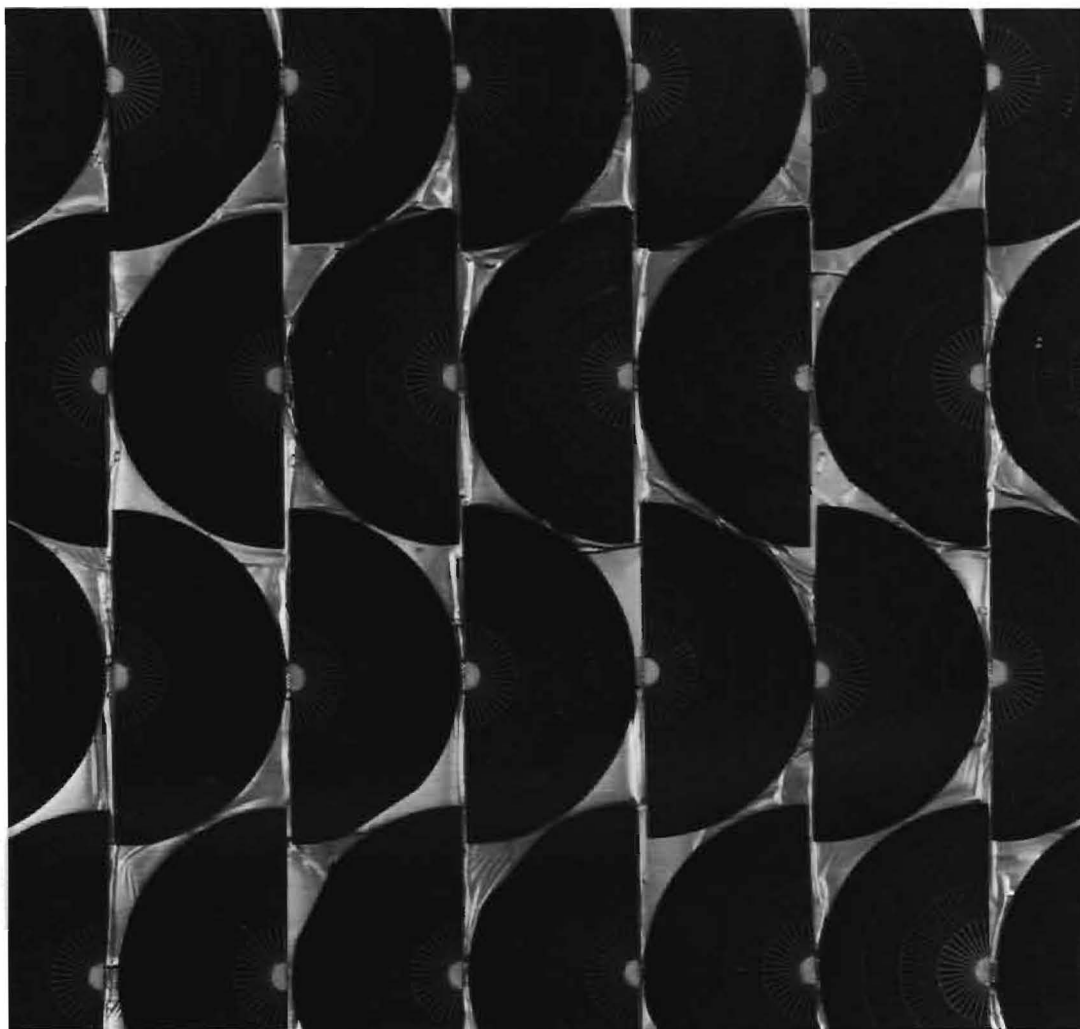
ARMY ANALYSIS PROGRAM

In 1982 Caltech initiated for the U.S. Army an Army Analysis program.

The request was made by the Army in response to its need for an objective, external analysis center to assist the Army in improving its efficiency and effectiveness. The program's studies will be directed to high-priority, long-term needs of the Army in the broad areas of national security, force deployment, supporting service, and military technology.

ARMY ALL SOURCE ANALYSIS SYSTEM

JPL was selected in 1982 to conduct the development of a joint U.S. Army and U.S. Air Force Tactical Intelligence Collection and Analysis System. The Army All Source Analysis System (ASAS) and the Air Force Enemy Situation Correlation Element (ENSCE) will use common hardware and software, with limited specialized software, to meet the requirements of the two services. The initial systems developed will probably utilize some commercial hardware to meet initial early-delivery requirements. Subsequent hardware and software improvements will be incorporated to meet military operational and environmental requirements.



Solar test panels

Despite the declining federal emphasis on energy research and development, JPL's Office of Energy and Technology Applications continued to develop innovative concepts in the areas of fossil fuels, solar energy, energy systems, and energy conservation technology. Work was also conducted on biomedical technology

and the application of space technology to other civil problems. In addition to the Department of Energy (DOE), sponsors include NASA and several other federal agencies, as well as state governments, industrial associations, and a variety of individual industrial concerns.

PHOTOVOLTAICS

During 1982, DOE's role in photovoltaics was redirected away from commercialization and market development and significantly toward the kind of long-range, high-risk research and development that is typically beyond industry's capability or willingness to perform with its own resources.

The Flat-Plate Solar Array project achieved a key advancement toward inexpensive silicon refinement for photovoltaic technology. The Union Carbide Corporation's experimental process system development unit was completed in late 1982. Work on the unit initially funded by DOE is now funded by Union Carbide. Experimental operation will be vital in verifying the quality and economics of silicon hydrides (silane) that can be produced in future production plants. High-quality silane could be used to manufacture amorphous silicon (thin-film) solar cells or converted into polysilicon, which is needed for making crystalline silicon solar cells. A study of a silane-to-silicon process, with deposition in a 2-inch-diameter fluidized-bed reactor (FBR), was successfully completed at JPL, and experimental studies were started on a 6-inch FBR. It is anticipated that Union Carbide will operate the experimental unit with a larger FBR.

An automated unit for growing multiple ingots through melt replenishment was developed and is now being sold commercially. Progress continued in the production of silicon ribbons, using continuously replenished melts.

SOLAR THERMAL POWER SYSTEMS

The development and testing of mirrored parabolic dish modules for producing electricity continued in 1982. A module consists of an 11-to-12-meter (36-to-40-foot) parabolic reflector. The reflector continually tracks the Sun and collects and focuses concentrated heat into a cavity receiver in the center of the dish, concentrating heat up to 15 times the intensity provided by the Sun alone. A heat engine/alternator converts the



Electricity is produced by this JPL solar thermal test dish equipped with an organic Rankine-cycle engine.

heat to electric power. The electricity produced is fed into the local utility grid.

A solar concentrator powering a Stirling engine demonstrated 29 percent efficiency in converting solar radiation to electricity, higher than any other solar energy conversion system. The testing was performed at the Parabolic Dish Test Site at JPL's Edwards Test Station in California's Mojave Desert. The Stirling, a four-cylinder external combustion engine using hydrogen as its working fluid, was tested at the focal plane of the dish. The assembly has generated 25 kilowatts of power, which was fed into the Southern California Edison grid during the tests.

Other developments included fabricating and testing a new parabolic dish concentrator at JPL's Edwards test site. The design uses fiberglass-reinforced panels with an aluminized reflecting surface. It is being tested with an organic Rankine-cycle heat engine using toluene as a working fluid. Electricity is produced by a permanent magnet alternator mounted on the turbine-pump shaft. The module is the prototype for a 100-kilowatt solar-dish experiment in Osage City, Kansas.

A third technology, an air-Brayton-cycle heat-engine module based on an advanced gas-turbine automobile engine design, is being tested with a solar thermal system. The Stirling, Rankine, and Brayton engines are being

developed and tested to determine the most cost-effective designs for dish/electric systems.

SOLAR THERMAL FUELS AND CHEMICALS

The potential of solar energy in chemical and fuel production is being investigated. A key experiment in 1982 confirmed that qualities unique to solar thermal energy—such as high temperature, high flux and heating rates, and photochemical properties—significantly sped the decomposition rates of metal sulfates. The test results show promise for the use of metal sulfates in the thermochemical production of hydrogen.

ENERGY SYSTEMS FOR INDIA

A program to introduce energy systems based on renewable energy re-

sources into rural communities in India is being conducted by JPL and the government of India through NASA and the Agency for International Development. The project involves the design, development, installation, and evaluation of both a suitable solar photovoltaic system and a point-focus solar thermal system.

The Indian village selected for this demonstration project is Salojipally, with a population of about 450 people. Agriculture is the village industry. The nearest power line is 17 kilometers away and is overloaded. The government of India has estimated that it would be at least 15 years before the village could be connected to a conventional power grid.

The solar thermal system designed for Salojipally is a steam Rankine system, consisting of six concentrators and receivers with a centrally located steam engine. It is anticipated that the

A Stirling engine, together with this test dish, produces electricity at JPL's test site at Edwards Air Force Base.



42 solar thermal power plant will produce approximately 25 kilowatts of electricity, peak. The power provided by this system will be used mainly for irrigation. Eight tube wells have been drilled in the village farm lands and should double or triple the crops produced by the village.

The solar photovoltaic power plant will provide 7 kilowatts of electricity, peak, to power two irrigation pumps. JPL purchased and tested 128 4-kilowatt photovoltaic modules, and Central Electronics, Ltd., of India is producing a 3-kilowatt module for the project. The balance of the system will also be fabricated in India.

Both systems will also charge a battery to provide some street lighting and power a television. The project plan is to have both solar energy systems installed and operating in Salojipally by the end of 1983.

BIOENERGY

METHANOGENIC BACTERIA

Biologically derived materials are being studied as energy sources in basic and applied research projects. The JPL effort emphasizes genetic manipulation of biomass and its biochemical and thermochemical conversion to useful fuels and chemicals. The study of anaerobes and methanogenic bacteria is part of that effort.

A laboratory has been established for the study of methanogenic bacteria, with particular emphasis on their genetics. The study of two species—*Methanococcus voltae* and *Methanobacterium thermoautotrophicum*—has begun. Their sensitivities to ultraviolet light (to be used as a mutagenic agent) have been measured. A mutant resistant to bromo-



Special plastic glove box filled with nitrogen is used for genetic studies of methanogenic bacteria.

ethanesulfonate, a specific inhibitor of methane synthesis, has been isolated from *M. voltae*. A number of other mutants from *M. voltae* have also been isolated, representing the first mutants obtained from methanogens; these mutants will serve as tools for the further study of using genetic transfer to obtain desirable microorganism characteristics.

CONVERTING AGRICULTURAL WASTE TO DIESEL FUEL

Agricultural debris, such as sugar cane wastes (bagasse), corn cobs, and cotton-seed hulls, is being examined as a source of liquid fuels and chemicals. A JPL effort has been designed to improve the extraction of commodities like furfural and butyl alcohol from the principal components of these agricultural wastes. Work has shown that a JPL-developed hydrolysis process will allow the production of multiple products through *Clostridia* fermentation (the conversion of organic materials into fuels and chemicals).

One of the products, furfural, is used in refining premium-grade motor oils. Butyl alcohol is a valuable fuel extender and an indispensable extractive agent in the manufacture of fine chemicals and pharmaceuticals.

UTILITY SYSTEMS

The Utility Systems program is developing technologies needed for electric power systems of the future. These technologies include communications and control, the integration of new energy sources, and conservation.

Controllers for substations and dispersed energy sources were the subject of two design studies for DOE. Several tasks are being performed in the development of power conditioning technology for the integration of DC sources, especially photovoltaics, into the utility grid. Transformerless power-conditioning subsystems are being modeled using a digital computer, and the analysis addresses various control schemes and failure modes. A 60-kilowatt inverter that

extends the state of the art using solid-state technology and is targeted for efficiencies greater than 96 percent is under development. A report has been released on utility interface issues associated with three-phase systems.

COAL ENERGY SYSTEMS

Erosion and corrosion of valves used to control coal slurry flows is a continuing problem in coal processing. JPL is developing a solution to the problem for DOE. A pseudo-porous plug allows for small increments of gas pressure relief so that the flow never achieves a velocity high enough to cause serious erosion by particles in the slurry.

The initial portion of the study consisted of the design, preparation, testing, and analysis of fluid flow using air as a single-phase medium. This test was designed to provide validation of the design philosophy and comparative data for subsequent two-phase and three-phase hydrodynamic flow testing and analysis.

The pressure letdown valve used in the air test consisted of a number of stages of letdown elements. Each letdown element is a partition in the form of a flat plate, each of which contains a selected number of orifice holes of specific cross-sectional area. The first partition has very few holes in it, but each succeeding partition has a greater number of holes to accommodate the increased volumetric flow of the gas as the pressure is successively reduced. Tests and analysis are conducted at Edwards Test Station.

CALIFORNIA METHANOL ASSESSMENT

Methanol is receiving increasing attention by both federal and state governments as a potential competitor to petroleum. It has been successfully demonstrated technically in applications ranging from utility boilers to automotive engines. Methanol is attractive as a fuel because it is a domestic resource, and has no significantly detrimental impact on air quality.

A joint effort by Caltech's Chemistry Division and JPL has brought together sponsors from both the public and private sectors for an assessment of the prospects for methanol use in California. Results of the assessment indicate that the economics of producing and using methanol in the near future do not look favorable, but that the long-term outlook is promising. The study asserts that more development and testing of both production technology and utilization equipment are needed before the widespread production and use of methanol will occur.

ENVIRONMENTAL TECHNOLOGY

The JPL Microwave Atmospheric Remote Sensing System (MARS) measures temperature versus altitude from ground level to 10,000 feet, precipitable water vapor, and the liquid water content of clouds. This mobile system, mounted on a van, was demonstrated and calibrated in the field at several sites in the Los Angeles basin. MARS will be used to study smog episodes and in Caltech studies of acid fog and acid rain. Data from these measurements will be available to smog forecasters on a near-real-time basis via telephone communication with remote display terminals.

BIOMEDICAL RESEARCH

The Office of Biomedical Research, established in 1967, is conducting more than 30 research and development tasks for government and private medical and health agencies. Biomedical research and technology tasks draw on JPL capabilities in computer image processing, advanced materials research, and advanced instrumentation.

IMMUNOMICROSHERE RESEARCH AND APPLICATIONS

Immunomicrospheres are very small polymeric beads, labeled with antibodies. This labeling allows the spheres to interact with cells that initiate antigen-antibody reactions common to most biological systems. Through special engineering of the materials from which the beads are made and by choosing specific

antibodies, these interactions can be restricted to certain subpopulations of cells. For example, current work is aimed at using immunomicrospheres to carry potent medication to cancer cells and using immune reactions to prevent normal cells from being affected. In another effort, the polymeric beads are being used to detect and identify pathogens present in the environment in extremely small quantities. Theoretically, single molecules of any specified substance should be detectable. This technique will prove invaluable in uses such as determining trace contaminants in atmospheric pollution.

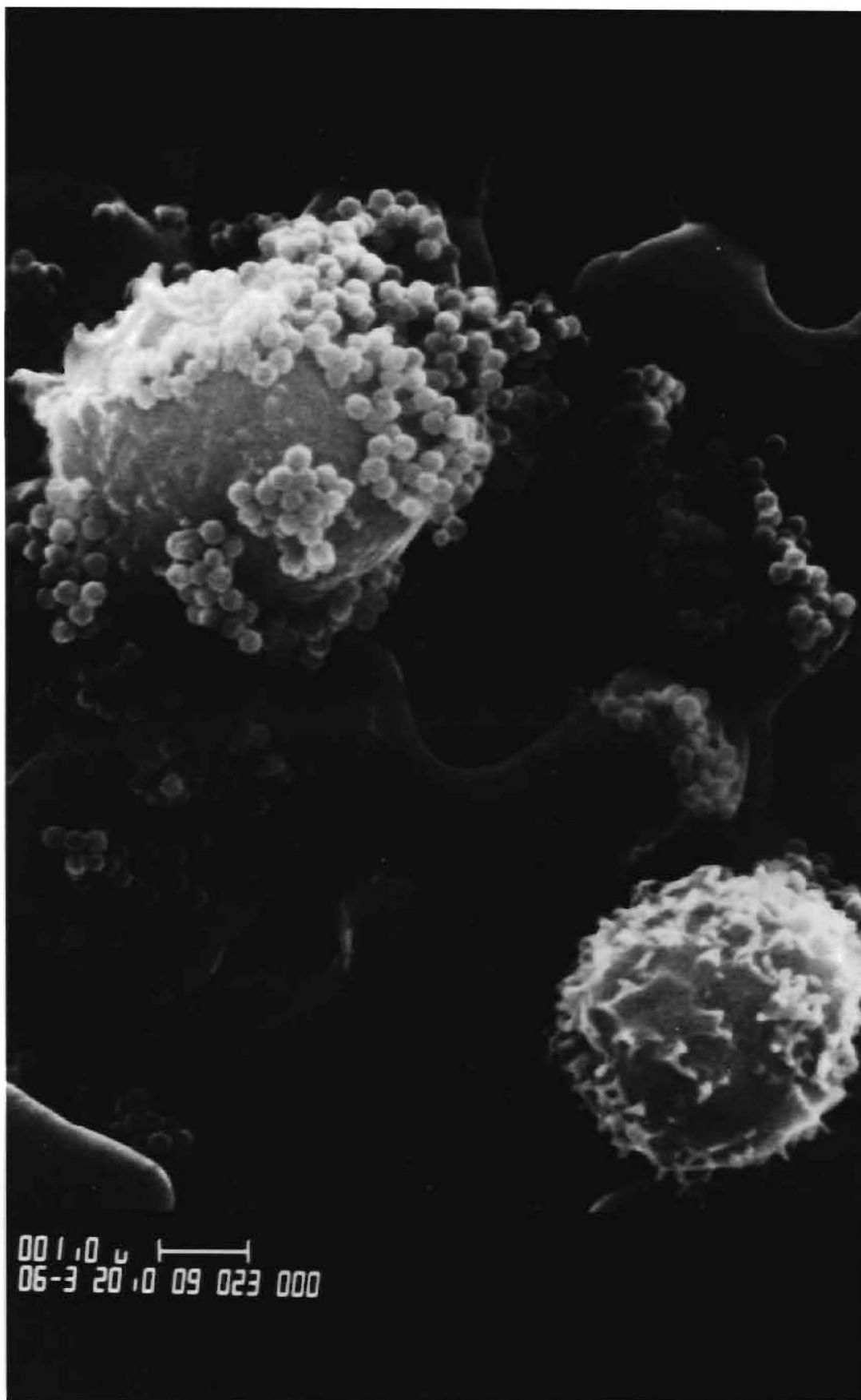
HYDROCEPHALUS SHUNT

Hydrocephalus, a condition most often affecting growing children, is characterized by an abnormal accumulation of fluid in cavities in the brain, which exerts pressure on brain tissues. This results in abnormal brain development, leading in many cases to severe retardation. Treatment for hydrocephalus is, in theory, simple: a perforated tube (shunt) is inserted into the affected cavity to drain off the excess fluid. Existing shunts, however, are less than satisfactory. JPL expertise in flow mechanics is being applied to study how fluids flow through small tubes and through even smaller perforations in tubes. Ion-beam technology developed for propulsion systems is being applied to "drill" perforations of sizes and configurations calculated to prevent clogging of the shunt and to permit appropriate drainage rates. Thus, JPL is providing both design specifications for an improved shunt and the technology necessary to implement them.

AUTOMATED PAP SMEAR SCREENING SYSTEM

A prototype Pap smear screening system continues under development at JPL with a grant from the National Cancer Institute. The system, which will process specimens at a rate of 1,000 cells per minute, will include a computer-controlled microscope and a high-speed imaging system composed of 16 microprocessors connected in a pipeline architecture. Each processor receives a cell

Immunomicrospheres attach themselves to a cancer cell but leave a normal cell alone.



- 46 image from its upstream neighbor, performs one part of the required processing on that cell, and passes it on to its downstream neighbor. By the time a cell image has passed through the pipeline, it can be classified as normal or abnormal. The host computer tabulates the proportion and type of abnormal cells and alerts the pathologists to those specimens that should be examined visually. The project is being conducted with the collaboration of the UCLA School of Medicine's Department of Pathology. The prototype will undergo testing at UCLA.

TRANSPORTATION TECHNOLOGY

COMPRESSED TELEVISION TRANSMISSION

Data-compression techniques for digital television images from NASA spacecraft have been implemented in microprocessors used in freeway traffic management. Existing traffic-monitoring systems use either microwave or coaxial communications links, both very expensive for extended freeway networks.

Other low-rate image transmission techniques do not provide the same picture quality and frame-update rates as those provided by the JPL techniques. A commercial firm has used the techniques to develop a prototype system that will be field-tested by JPL in 1983.

WIDE-AREA DETECTION SYSTEM

A crucial element for advanced traffic-control systems for urban streets and freeways is the sensor for measuring traffic flow. JPL is developing a remote-measurement device, the Wide-Area Detection System (WADS), based on image-processing and pattern-recognition technology for such traffic control systems. In testing, WADS demonstrated the detection, counting, and velocity measurement of individual vehicles simultaneously in four freeway lanes. Sensing accuracies under normal environmental and traffic conditions proved adequate for advanced traffic-control systems, but some refinements will be necessary to ensure accurate measurements during adverse conditions.

JPL TECHNOLOGY



Seasat radar image of the MacKenzie River Delta, Canada

***H**igh-technology research and development covers a number of areas at the Laboratory, including space science and engineering, information systems, and the development of new materials. JPL research and*

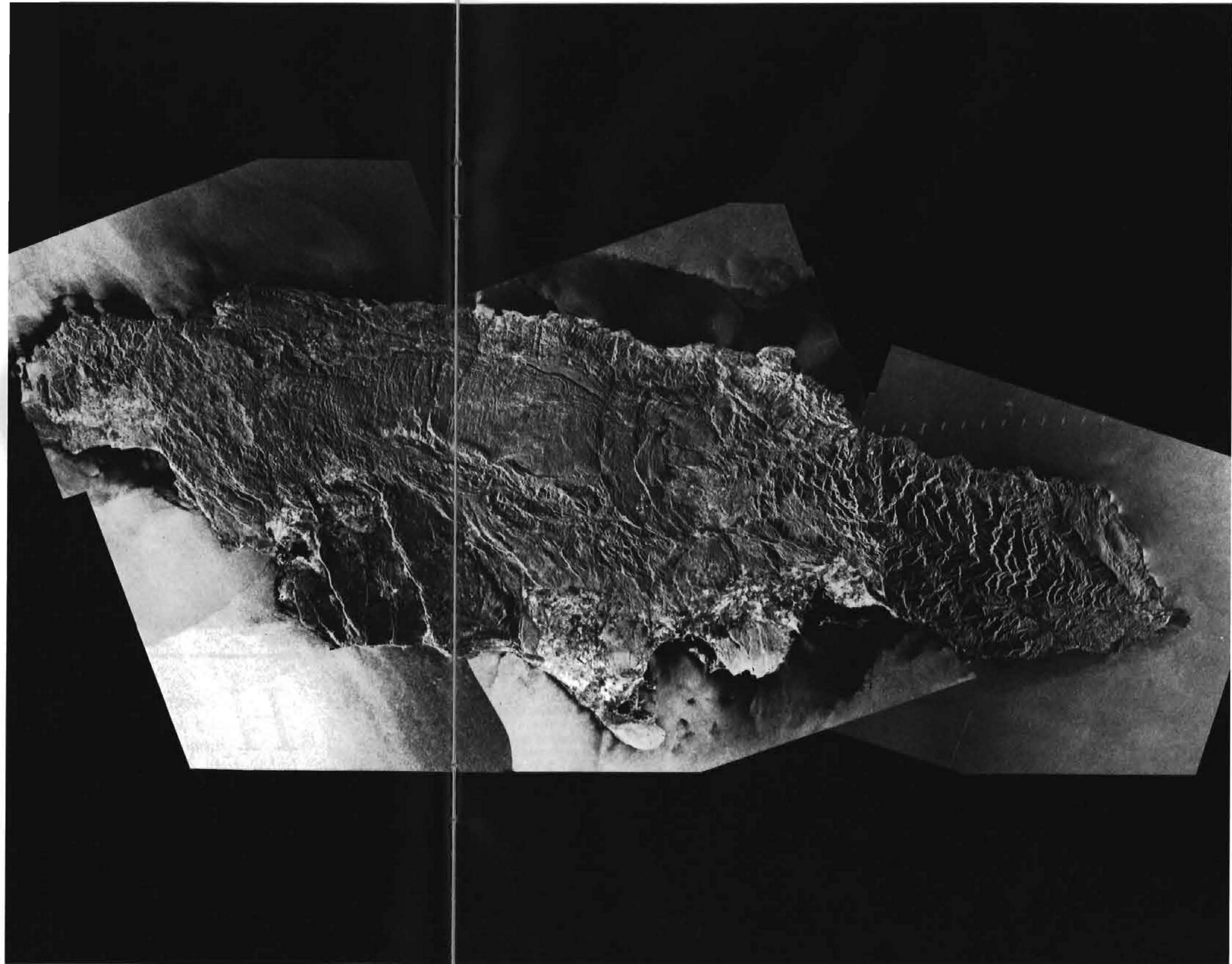
development activities have resulted in significant advances in fields such as cryogenics, information systems and data processing, propellants and fuels, materials utilization, and the very-large-scale integration of circuitry.

There has been a considerable increase in the need for the active cryogenic refrigeration of sensitive spaceborne detectors, as well as for high-thrust, space-storable cryogenic fuels. Since most deep-space missions and many Earth-orbiting missions require extremely long operating times (up to ten years), a refrigerator with a very long lifetime is required. Due to the wearing out of moving parts in mechanical refrigerators, there is presently no way to provide active cryogenic cooling in space for these very long periods.

To answer this need, JPL has fabricated and started testing a hydride refrigerator with no moving parts, other than long-life valves. A long-life metallic powder, LaNi_5 , absorbs hydrogen at room temperature and pressure, then compresses the hydrogen to 40 atmospheres when heated to 100 degrees Celsius. By flowing the high-pressure hydrogen through regenerative heat exchangers and expanding the gas through a valve, temperatures as low as 20 degrees Kelvin (-253 degrees Celsius) have been obtained by the three-compressor system. The system can operate on low-temperature waste heat (100 degrees Celsius) or direct solar heat.

SYNTHETIC APERTURE RADAR DATA PROCESSING

JPL has made major advances in processing synthetic aperture radar (SAR) data to yield high-resolution pictures. The existing ground processing system has used special-purpose array processors with conventional computers. An order of magnitude increase in processing speed is expected in the future, when conventional computers are replaced with special-purpose computers. The JPL facility has supported the Seasat mission and will support future space shuttle, planetary, and Earth-orbiting satellite missions.



Digitally processed Seasat radar image mosaic of Jamaica.

50 **INFORMATION SYSTEMS
TECHNOLOGY**

Major components of a self-checking, flight-data-system computer were developed in 1982. A processor interface building block and memory interface building block were successfully fabricated and tested. The components, together with other components still being developed, will allow a spacecraft computer to be built that will be nearly fail-safe, as well as tolerant of harsh environments and data errors.

The Laboratory has also developed, and tested by computer simulation, on-board computer algorithms that would reduce by a factor of 100 to 500 the amount of data transmitted from an interplanetary spacecraft to Earth for optical navigation purposes. The algorithms would use spacecraft television pictures of planets, moons, asteroids, comets, and stars to help target the spacecraft and its science instruments toward those bodies during a close flyby. It was demonstrated that the few hundred television pictures taken for optical navigation at Jupiter and Saturn by Voyager could have been reduced to a volume of data equivalent to

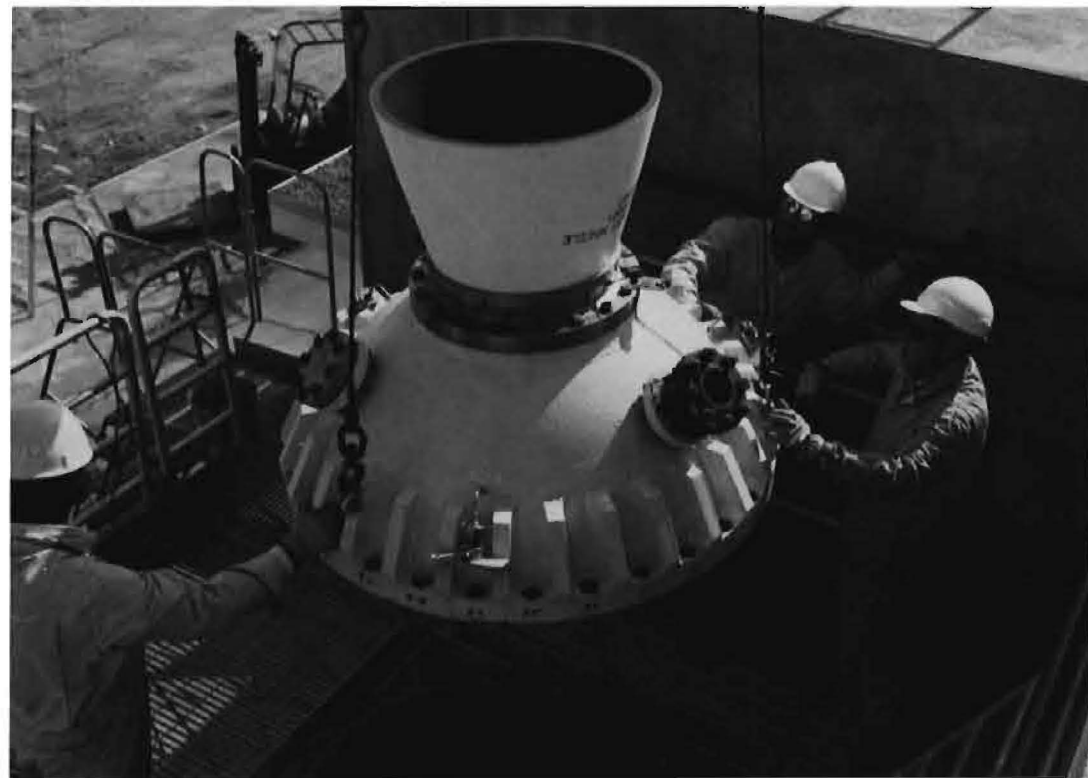
only one picture, had this technology been available. Both the self-checking and optical-navigation technologies are being targeted to Mariner Mark II types of missions.

PLANETARY IMAGE VIDEODISC

In the past year, JPL's Planetary Image Facility began distributing copies of the first Planetary Image Videodisc to planetary geology researchers around the United States. The analog encoded optical disc contains more than 100,000 images of Mercury, Venus, Mars, and Jupiter taken by the Mariner, Viking, and Voyager planetary missions. An equivalent number of 8-by-10-inch photos would require nearly 300 cubic feet of storage space (16 cabinets containing 666 binders).

**MICROWAVE BURNER SYSTEM
FOR MEASURING SOLID-
PROPELLANT COMBUSTION-
RESPONSE FUNCTION**

Avoiding or minimizing combustion instability or burning irregularities is



Rocket-motor, propulsion, and rocket-fuel testing is performed at JPL's Edwards Test Station, Edwards Air Force Base, California

an important consideration in the design and development of any solid-propellant rocket motor. Such instability occurs as the result of the behavior of the burning propellant when exposed to some type of unsteady pressure or velocity fluctuations. The instability is strongly influenced by the composite or heterogeneous nature of the propellant.

A prototype microwave doppler velocimeter system for directly measuring the pressure-coupled combustion-response function of solid propellants over a broad frequency range has been developed by JPL for the Air Force Rocket Propulsion Laboratory (AFRPL). A demonstration consisting of more than 80 test firings of eight different propellants was completed in 1982, and the system is due for transfer to AFRPL.

**ANTIMISTING FUELS
TECHNOLOGY**

JPL successfully demonstrated a new system for producing antimisting aircraft fuel. Antimisting fuel, a combination of conventional jet fuel with very small amounts of a polymer developed by Imperial Chemical Industries, resists ignition after a shock. If successfully applied, it could sharply reduce the number of fires from aircraft crashes. Based on laboratory data, a system for producing antimisting fuel has been developed that meets fire protection and engine compatibility requirements. The concept was successfully demonstrated at the Federal Aviation Administration's Technical Center, Atlantic City, New Jersey.

**OXYGEN AND IRON MADE FROM
LUNAR ROCK**

A significant step toward utilizing lunar materials was achieved in 1982 when gram quantities of iron metal and oxygen gas were made from simulated lunar rock. The method of magma electrolysis, using heat and electric current, was used to produce oxygen and iron from molten rock. Oxygen produced through this method can be used for life-support and propulsion on the Moon at great savings over importing oxygen



A conventionally fueled airplane bursts into flame in test crash (top). An airplane carrying JPL-developed antimisting fuel resists combustion on impact (bottom).



from Earth. The process consists of passing a current through molten rock, which releases oxygen at the anode and metal at the cathode. It can be performed at temperatures less than the melting point of iron. Methods for refining iron for structural purposes, as well as methods for producing such metals as magnesium, aluminum, and titanium, are being explored.

52 **MAGNETIC SPUTTERING
DEPOSITION OF AMORPHOUS
METALS**

An industrially practical process involving vapor quenching (magnetron sputtering) has been applied to the creation of a new alloy of a relatively new class of materials—amorphous metals. Such metals have extraordinary mechanical, chemical, and magnetic properties as a consequence of their non-crystalline structure. In the past, amorphous metals have been fabricated only as ribbons or wires, by liquid quenching, in contrast to the large-area, thin films now possible. Moreover, prior materials had a rather low upper use temperature while the new alloys can be made much more refractory. Current work is concentrated on the macro and atomistic structures of the films, since it is these structures that, for a given alloy, govern its properties. While liquid-quenched amorphous metals have a corrosion resistance far superior to that of the same metals in

their crystalline form, early results show that the corrosion resistance of vapor-quenched films is superior even to that of amorphous alloy ribbons prepared by liquid-quenching techniques.

CUSTOM VLSI CIRCUITS

Custom integrated circuits are currently being designed at JPL for a number of applications such as image filters and data correlators. Future advanced systems will require circuits with the complexity of very-large-scale integration (VLSI), where the number of gates exceeds 10,000. At JPL, such circuits will be designed in-house using the Laboratory's VLSI computer-aided design facility, be fabricated at specialty manufacturers known as silicon foundries, and be qualified in-house using advanced product-assurance methods. Such an approach is expected to provide reliable and affordable custom VLSI parts that can be fabricated on a timely basis (estimated at three months).

INSTITUTIONAL ACTIVITIES



After a nationwide search conducted by a selection committee of Caltech Trustees, Caltech faculty, and senior Laboratory personnel, Dr. Lew Allen, Jr., was named Director of JPL and a vice-president of Caltech in July 1982. Dr. Allen accepted the appointment after retiring from the U.S. Air Force, where he held the rank of general

and was Air Force Chief of Staff and a member of the Joint Chiefs of Staff. He began his Caltech-JPL appointment on October 1. Dr. Allen replaced Dr. Bruce C. Murray, who resigned the directorship of JPL as of June 30, 1982, after six years of service. Deputy Director Charles Terhune served as acting Director during the interim.

54 OFFICE OF ENGINEERING AND REVIEW

The Office of Engineering and Review's primary responsibility is to develop and maintain an effective reliability and quality-assurance activity in support of the Laboratory's programs. The Office also evaluates engineering policies and standards and assesses technical risks associated with major Laboratory commitments.

During 1982, a formal reporting system was initiated to provide an independent assessment of the risks of all flight projects and flight experiments. Twenty-three formal reviews were conducted.

DIRECTOR'S DISCRETIONARY FUND

The Director's Discretionary Fund (DDF) provides resources for independent research and development in promising fields of science and engineering. It emphasizes innovative and seed efforts for which conventional funding is not available, and it strongly encourages collaborative work with faculty and students at Caltech and other universities. The current funding level is \$1 million per year. About 250 tasks, dealing with very diversified subjects, have been funded since the inception of the DDF. Tasks that win support are selected from about 100 worthy proposals considered annually. Competition is keen, and the dollar value of the proposals usually exceeds the funds available by a factor of four or five. In 1982, 18 major and seven relatively small new tasks were initiated, and seven ongoing tasks received modest second-year support.

CALTECH PRESIDENT'S FUND

The NASA-Caltech Memorandum of Understanding provides for the President's Fund, which funds collaborative efforts between JPL staff and both faculty and students from Caltech and other universities.

NASA contributes up to \$350,000 a year to the Fund on a matching basis.

In 1982, about 15 new tasks were initiated with President's Fund support, while some 25 other tasks were still in progress. Besides Caltech, the schools involved include the University of Arizona, the University of Chicago, the University of Southern California, Penn State University, Cornell University, Stanford University, the State University of New York, and five campuses of the University of California.

NASA HONOR AWARDS

The NASA Honor Awards program provides special recognition of outstanding individual and team efforts. In 1982, 21 individuals and five groups were recognized:

NASA Distinguished Service Medal
Bruce C. Murray and
Charles H. Terhune, Jr.

NASA Outstanding Leadership Medal
Kirk M. Dawson and
Nicholas A. Renzetti

NASA Exceptional Scientific Achievement Medal
Charles Elachi and
Alexander F. H. Goetz

NASA Exceptional Engineering Achievement Medal
John A. Garba and James R. Janesick

NASA Exceptional Service Medal
Marshall E. Alper, Robert J. Beale, James F. Blinn,
Mary L. Brownell, Gerald H. Copeland,
William C. Frey, James L. Granger, Mark Herring,
James W. Layland, David D. Norris, Glenn A. Sisk,
Paul T. Westmoreland, and William M. Whitney

NASA Group Achievement Award
The NASA Office of Inspector General at JPL,
the Scanning Multichannel Microwave Radiometer
Team, the Shuttle Imaging Radar Development
Team, the Shuttle Multispectral Infrared Radiometer
Team, and the Voyager Photopolarimeter
Investigation Team

VISITING SCIENTISTS

Participants in the Distinguished Visiting Scientist Program, which was initiated by the Director in 1979, continued to provide short-term consultation on important JPL projects.

The distinguished visiting scientists are Professors Klaus Hasselmann, Germany; Jacques Blamont, France;



- 56 Michael S. Longuet-Higgins, England; Giuseppe Colombo, Italy; Hugo Fechtig, Germany; and Peter Niler, Eugene Shoemaker, and Richard Goody, all of the United States.

Under a Faculty Fellowship Plan sponsored by NASA, the Department of Energy, and the American Society for Engineering Education, 33 other professors from U.S. campuses spent the summer in residence. They made significant contributions to JPL projects and carried valuable practical experience back to their students.

PATENTS AND TECHNOLOGY UTILIZATION

The Office of Patents and Technology Utilization evaluates, patents, and helps NASA publicize the many inventions and technological innovations resulting from JPL work. In 1982, 211 inventions and innovations were disclosed to NASA and other sponsors of JPL.

The U.S. Patent Office issued 39 patents to Caltech and NASA for JPL inventions. The Office also helped NASA and Caltech identify potential licensees who had an interest in NASA- or Caltech-held patents, issued or pending. Caltech's record of licensing more than one-third of its patented JPL inventions was maintained.

The Office provided information on 33 JPL inventions and innovations reported in NASA's *Tech Brief Quarterly* and mailed technical information documents in response to almost 22,000 inquiries about JPL inventions.

ADMINISTRATION

Research and development costs for the fiscal year ending September 1982 were \$388 million, which represents a 3 percent decline from fiscal year 1981. Costs for NASA-funded activities amounted to \$318 million, a 3.0 percent increase over 1981. Energy and Technology Applications costs declined to \$45 million, a decrease of 41.6 percent compared with fiscal year 1981, while tasks for the Department of Defense amounted to \$22 million, a 69.2 percent increase over 1981. The JPL work force declined slightly during the year, from 4,778 to 4,590.

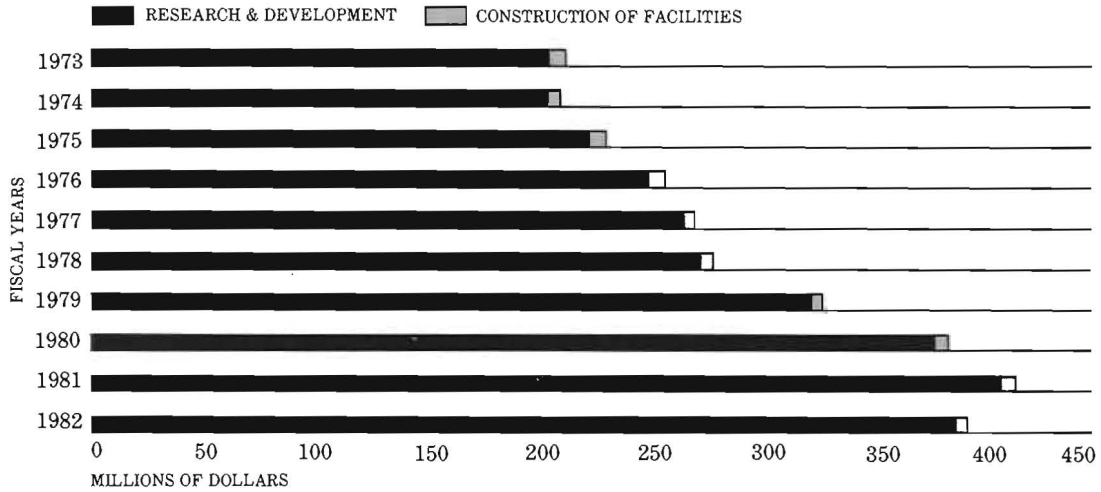
After more than twenty years of operation under Prime Contract NAS7-100, Caltech and NASA last year negotiated a successor contract, NASV7-918, for the continuation of research programs at JPL.

Procurement obligations in fiscal year 1982 totalled \$213 million and represented a 10.9 percent increase over the previous year. The increase primarily reflects additional procurement for NASA programs. Small business transactions increased by 36.4 percent to \$75 million, while transactions with minority-owned businesses reached \$10 million, a gain of 25 percent over the previous year.

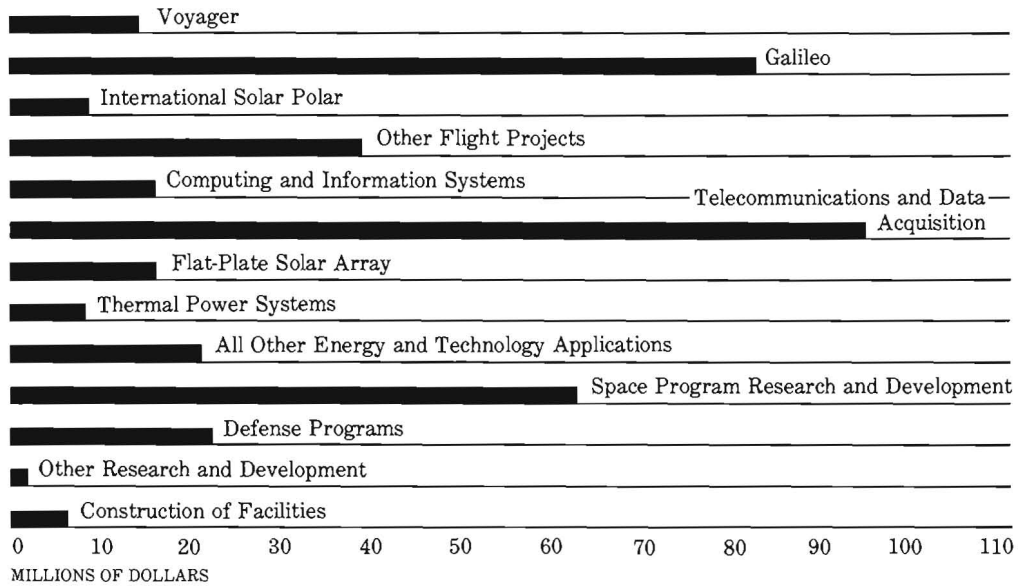
A new, ten-passenger Beech King Air aircraft was placed into daily service in 1982; it is used primarily to support the Edwards Test Station and the Deep Space Communications Complex at Goldstone. It also serves NASA's Dryden and Ames centers twice weekly.

TOTAL COSTS

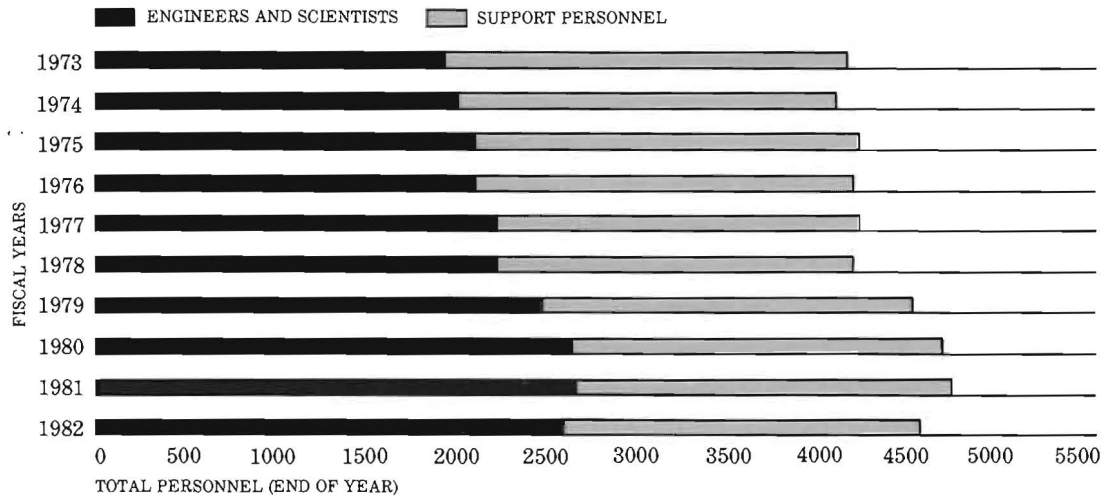
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FISCAL YEAR 1982 COSTS



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